Physical and Ecological Processes in Episodic Channels

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This is how we expect rivers to look—narrow, densely vegetated, filled with water, little visible sediment

This is different.
Without the water, we might not recognize it as a river.
If we did, we might want to restore it.

Plum Creek, Colorado, 1953

Plum Creek, Colorado, 1965

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Channel Variability Increasing →

Fluctuating Channel

Equilibrium Channel

Arroyo Cycle Influenced by Internal Thresholds

Sandbed Channel with Width Fluctuations Driven by Extreme Floods

Meandering Stream in Equilibrium with Frequent Flows

Alluvial Fan in Equilibrium with Extreme Floods

Constant Flow

Episodic Flow

Flow Variability Increasing →

Four Example River Systems

Channels in Equilibrium with Frequent Flows

Meandering channel in snowmelt-dominated watershed
Flow from regional, long duration precipitation
Low variation in flow within and between years
Erosion from rare floods is moderate, and recovery is rapid

Time-Varying Channels Driven by Episodic Flows

Sandbed Channel in small semi-arid watershed
Flow from local, short-duration extreme precipitation
High variation in flow within and between years
Erosion from rare foods is extreme, and recovery is slow

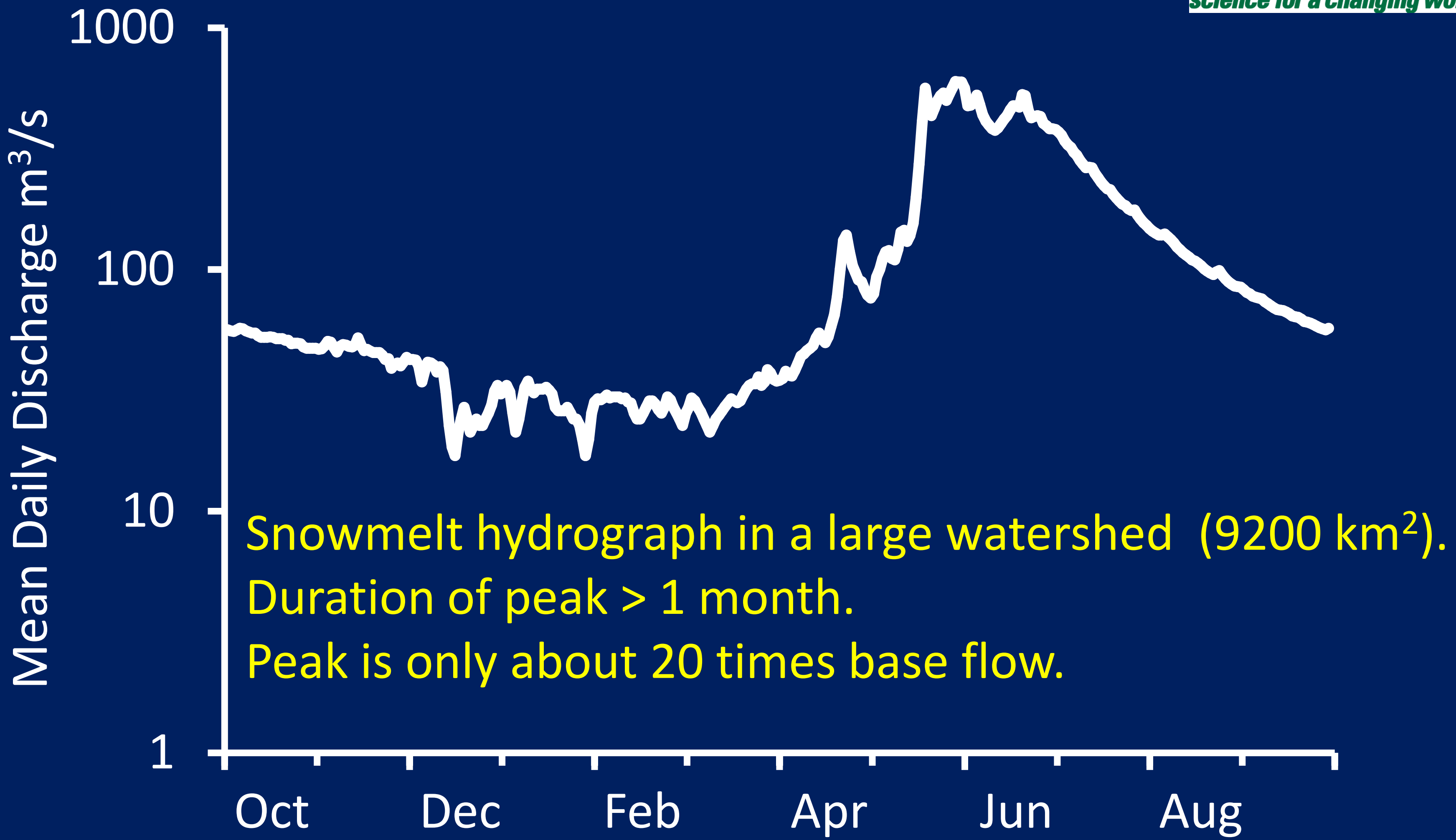
Channels in Equilibrium with Extreme Flows

Alluvial fan in arid watershed
Flow from local, short-duration extreme precipitation
Very high variation in flow within and between years
Channel is in equilibrium with extreme floods; no recovery

Time-Varying Channels Driven in part by Internal Thresholds

Arroyo in semi-arid watershed
Flow from local, short-duration precipitation
High variation in flow within and between years
Arroyo cutting and filling influenced by precipitation and internal controls

Yellowstone River near Livingston, Montana, Water Year 2009

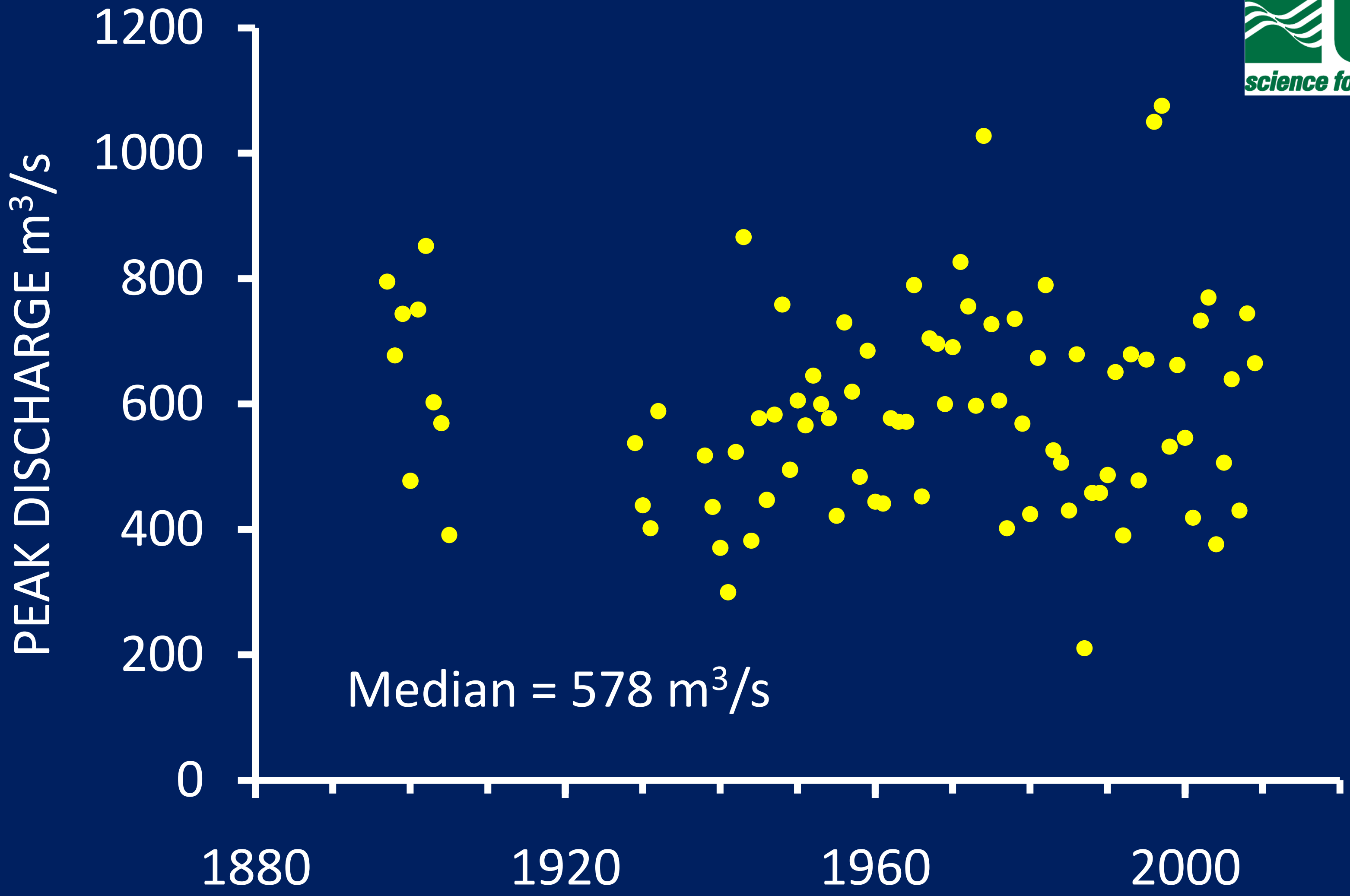


Yellowstone River near Livingston, MT. Peak instantaneous annual discharge.

The highest peak is less than twice the median.

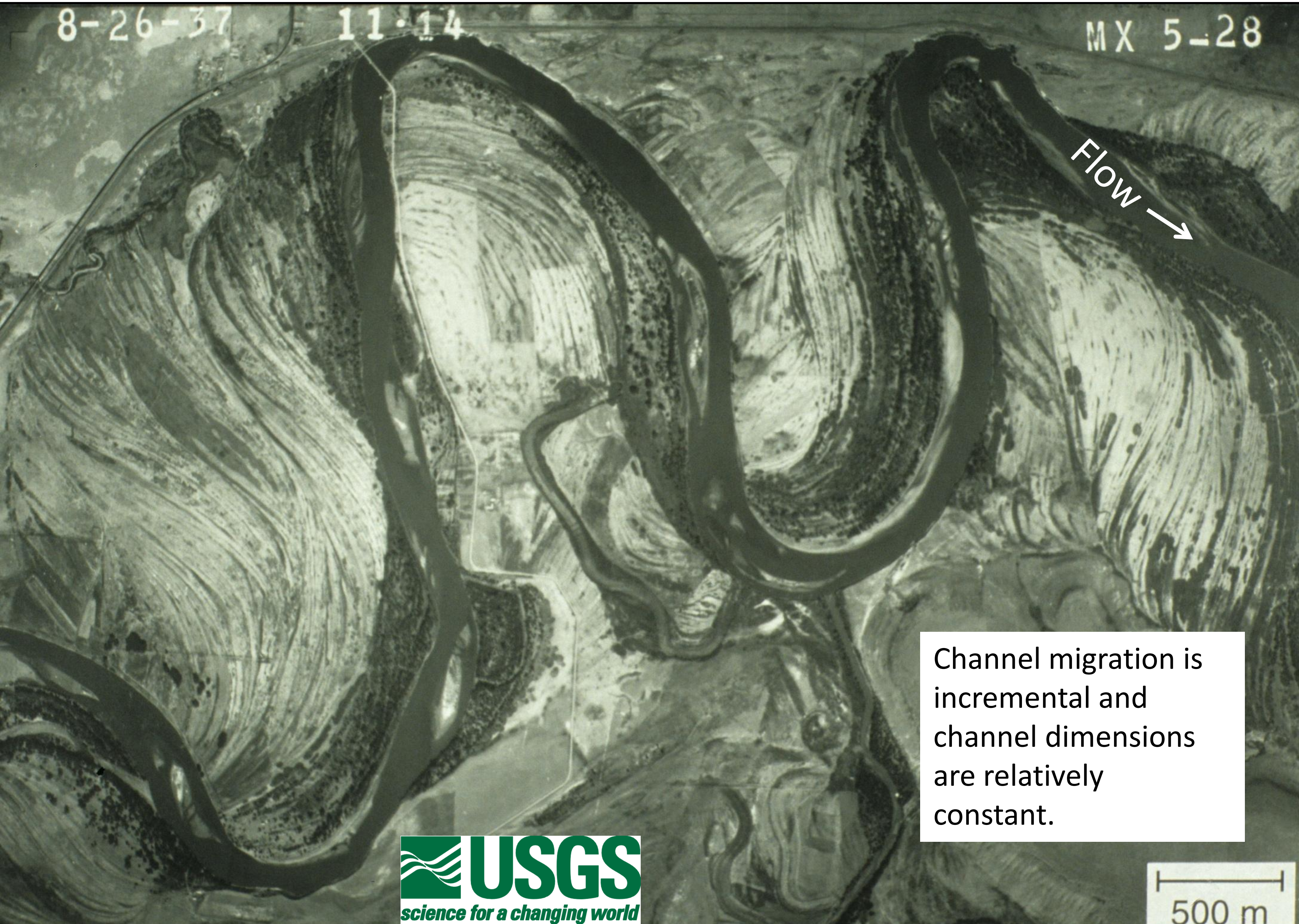
The biggest flows have only a modest effect on channel dimensions.

Because flows between high flows are large, recovery is rapid.



Point bar and cut bank along the Little Missouri River, Theodore Roosevelt National Park, North Dakota.

Missouri River, Montana, 1937, before most flow regulation, another snowmelt river

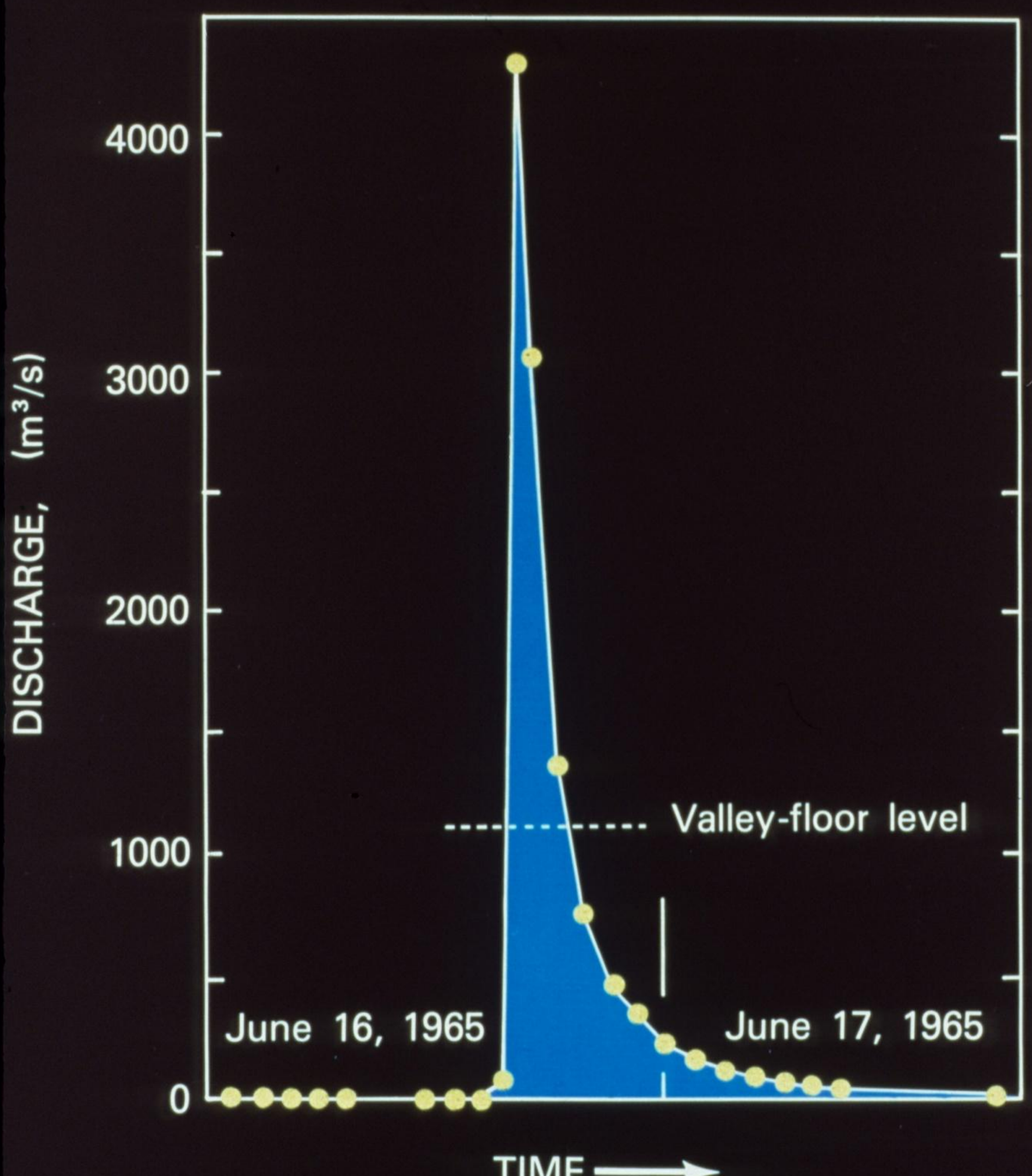


Channel migration is incremental and channel dimensions are relatively constant.

Time-Varying Channels Driven by Episodic Flows

Sandbed channels in small semi-arid watersheds of eastern Colorado
Flow from local, short-duration extreme thunderstorms
High variation in flow within and between years
Erosion from rare foods is extreme, and recovery is slow

Hydrograph of a thunderstorm flood along Plum Creek, CO, watershed = 782 km^2 The peak is four times larger than the biggest flows along the Yellowstone, but duration was only a few hours.



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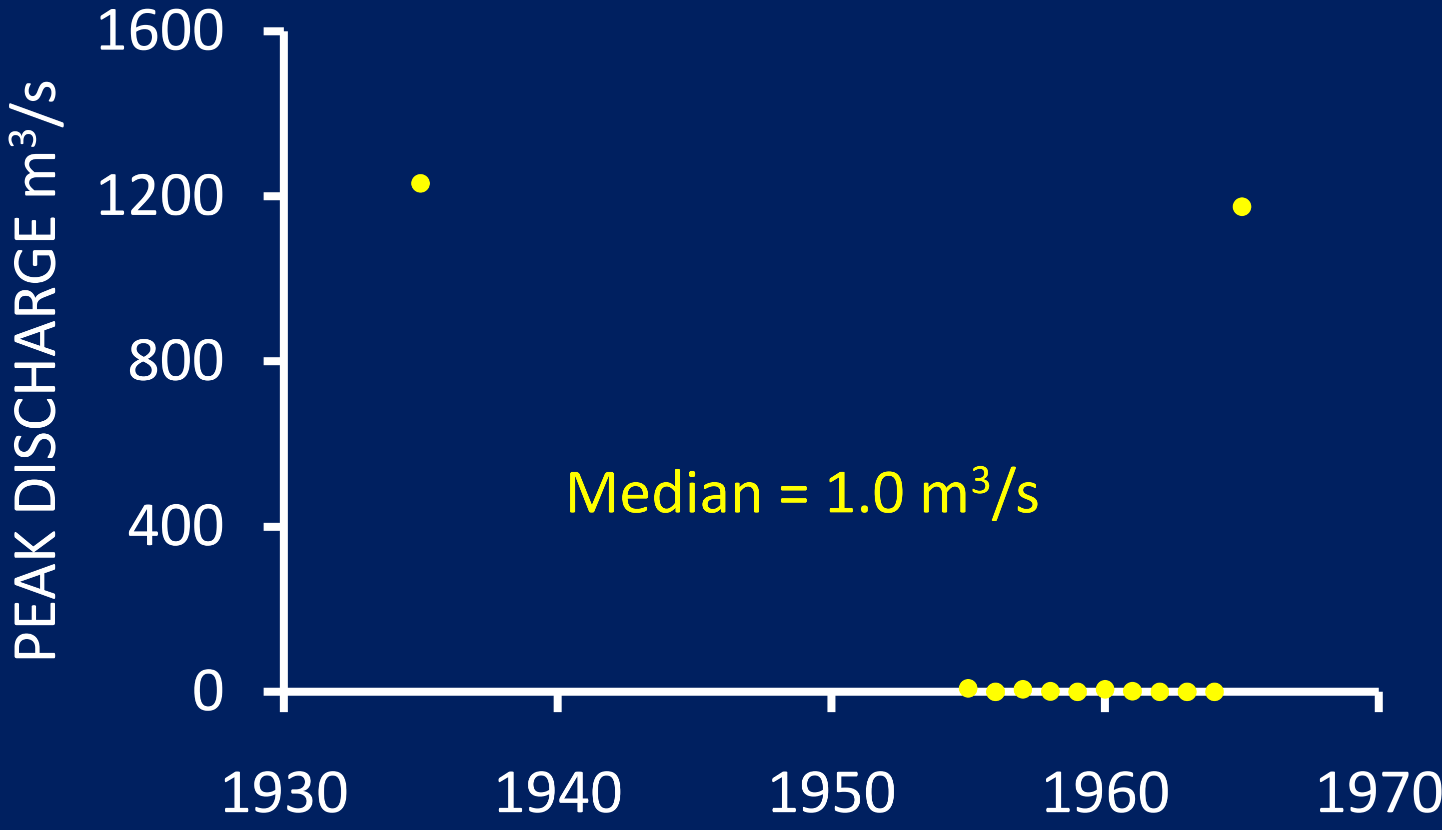
Kiowa Creek at Elbert, CO. Peak instantaneous annual discharge.
Summer thunderstorms in a small (74 km^2) semi-arid basin.

Most years, peak flows are negligible. Base flow is zero.
Highest peaks are 1000 times the median.
Flood effects are extreme, and recovery is slow.




Plum Creek 1964


Plum Creek 1967

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Plum Creek 1967


Plum Creek 1988

Plum Creek, Louviers, CO

Plant establishment with channel narrowing:

Plum Creek channel narrowing, continued

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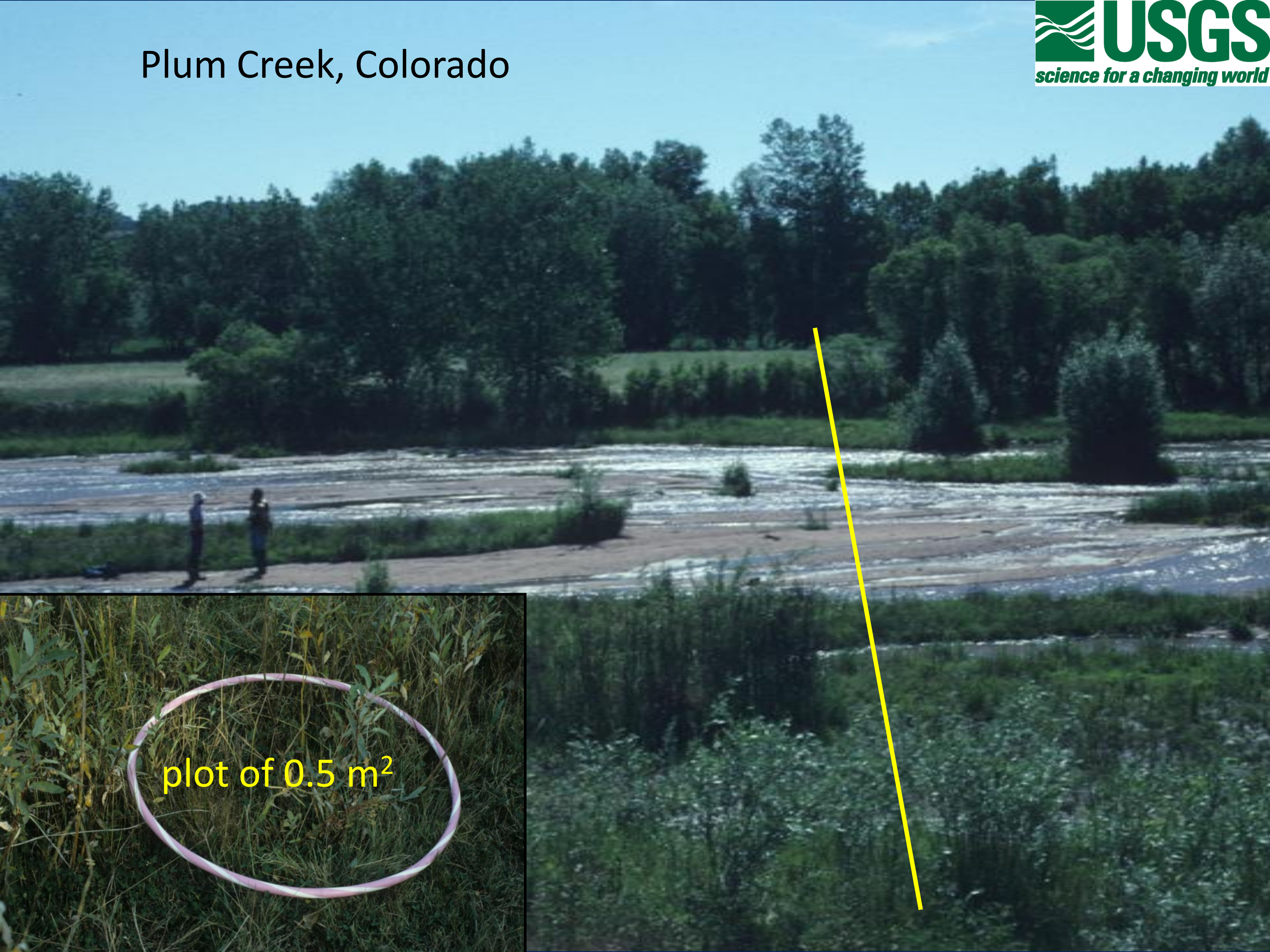
Plum Creek, Colorado



Summary Statistics for Plots by Age Class

There are many disturbance-dependent species at Plum Creek.
Note the decrease in the number of species per plot on older surfaces.
What would happen to these species in the absence of floods?

	Age (years)				
	0	1 to 4	5 to 18	26	>26
Fluvial Surface	Channel Bed	Vegetated Bar	Vegetated Bar	Terrace	Terrace
Mean Relative Elevation (m)	-0.02	0.11	0.42	2.45	2.41
Mean Vegetative Cover (%)	3	60	49	33	57
Mean Litter Cover (%)	1	14	76	37	69
Mean # Species/plot	3.4	17.8	10.2	5.4	5.0
Nativity	0.68	0.63	0.62	0.71	0.28
Perenniality	0.71	0.72	0.90	0.75	0.63
Number of Plots	71	65	120	28	57

Plum Creek, Louviers, CO

Does this need to be restored?

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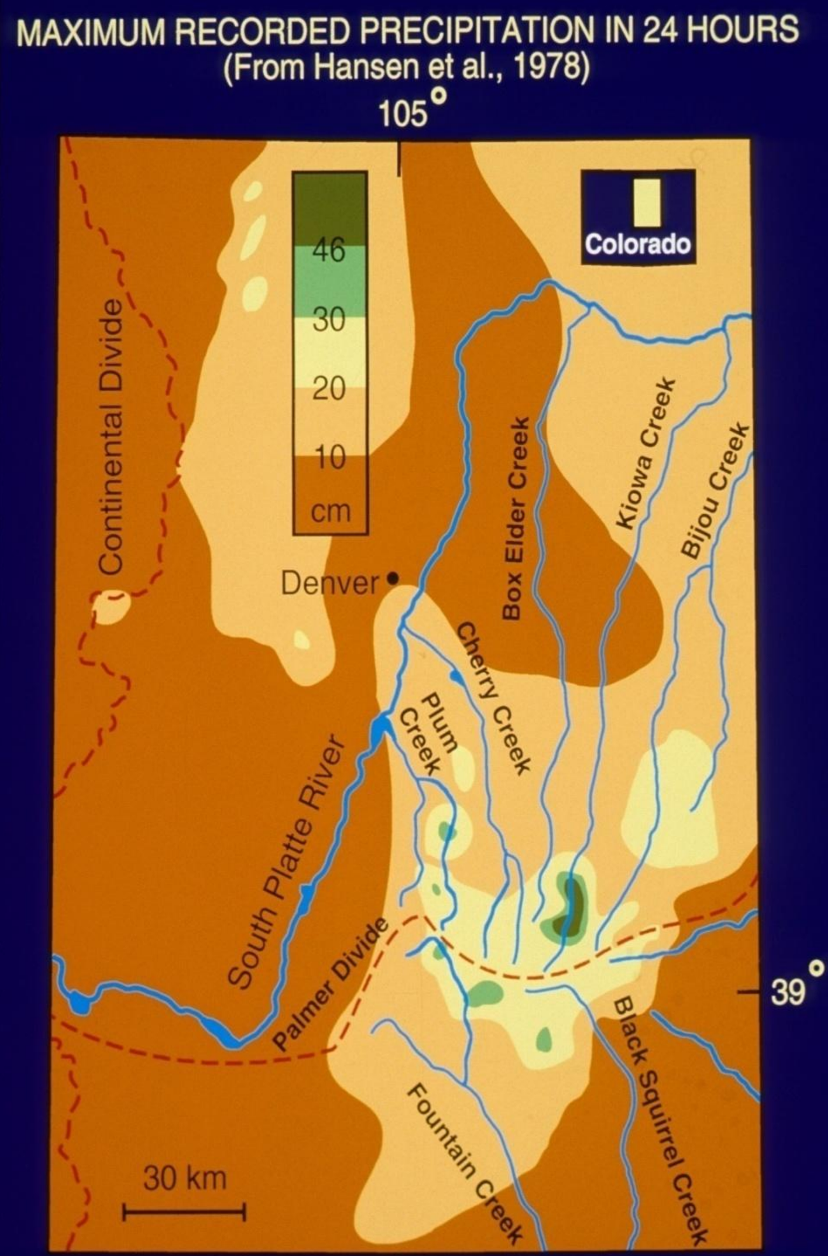
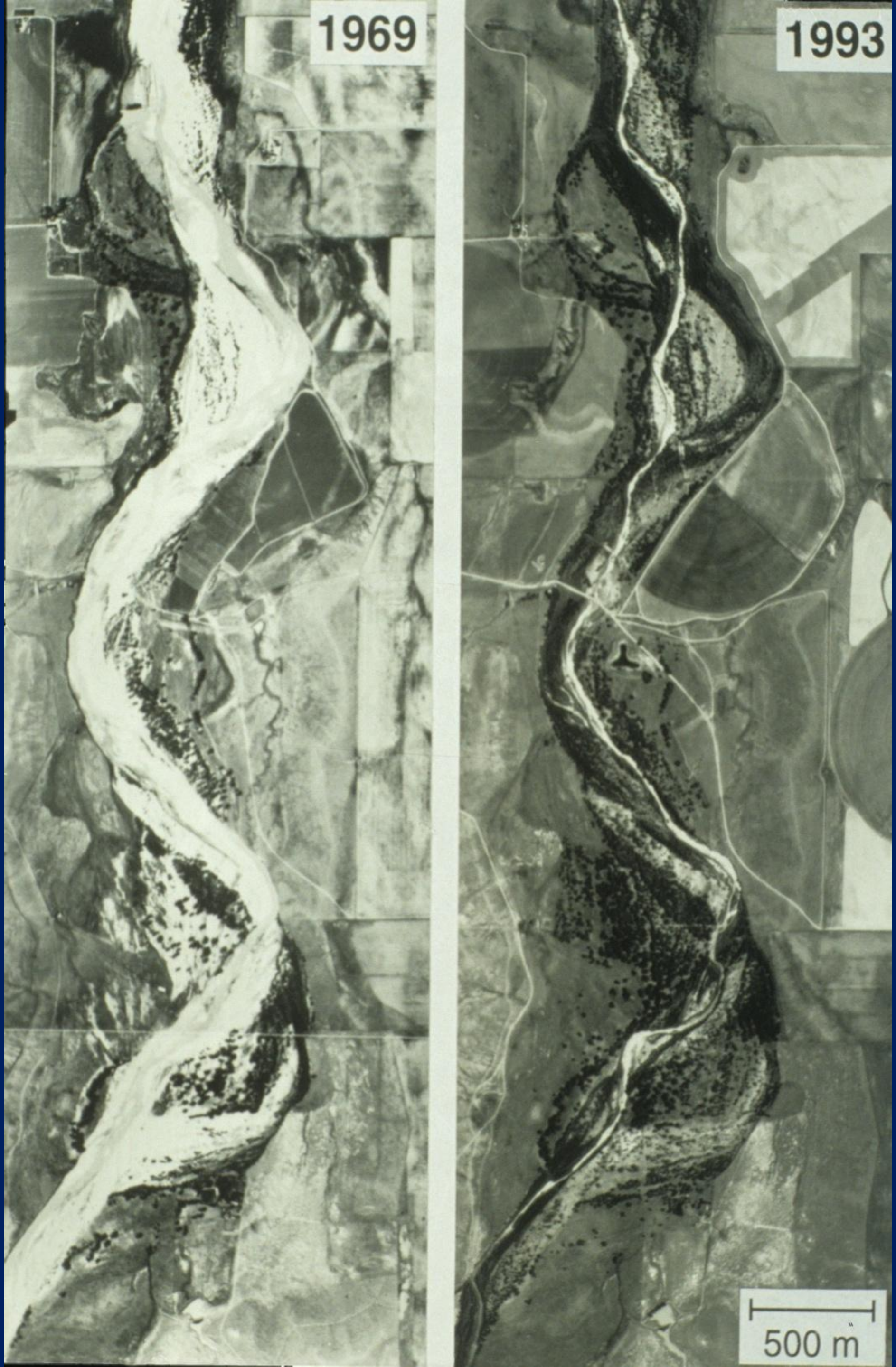
The precipitation event that caused the Plum Creek flood was extreme, but not unique for streams draining the Palmer Divide.

Mean annual precipitation is 45 cm.





West Bijou Creek also had a large flood in 1965.

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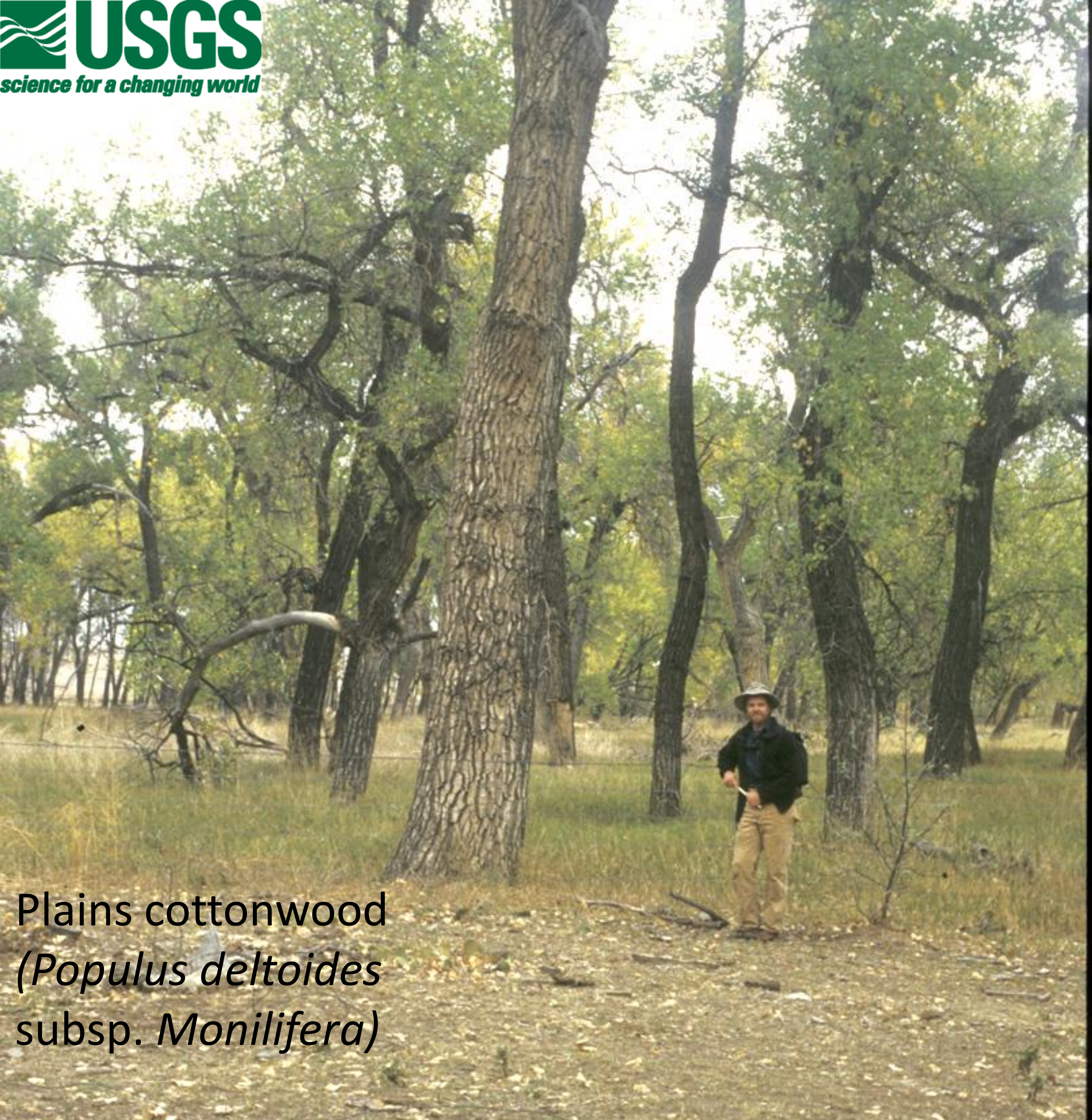


Plains cottonwood
(Populus deltoides
subsp. *Monilifera)*

Cottonwood is the most abundant riparian tree in the inland west.

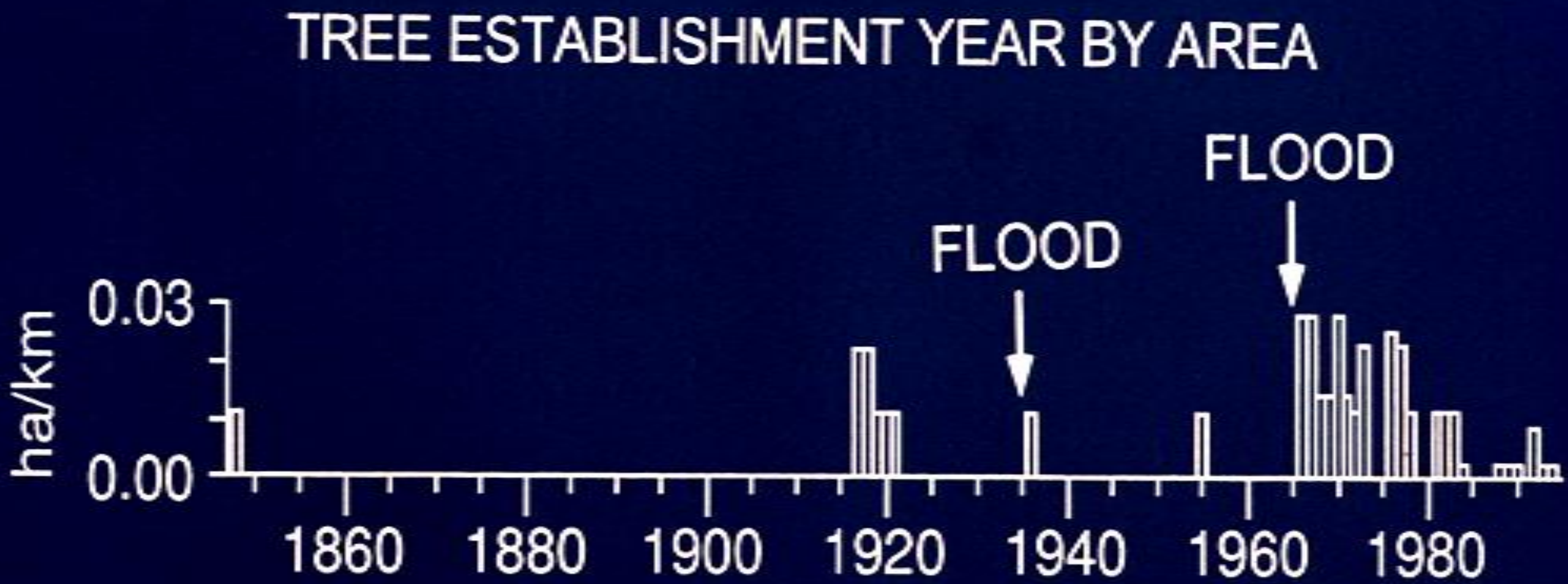
Forest patterns are determined by strict requirements for reproduction, which are rarely met.

Present cottonwood patterns reveal past history of flow variation.

Cottonwood seeds have broad dispersal
But strict establishment requirements:

Abundant moisture
Abundant light
Safety from future disturbance—Here only if the channel is narrowing

UPPER WEST BIJOU CREEK, CO



Area of forest as a function of establishment year.

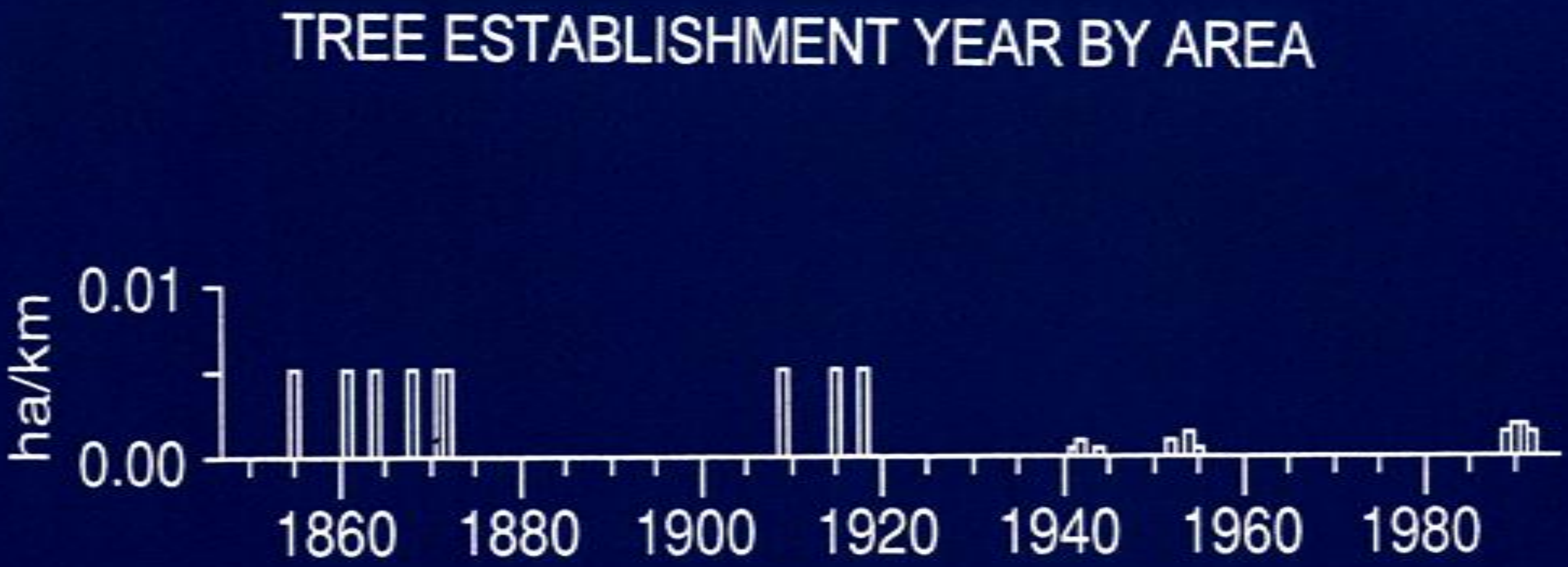
Why so little forest after the flood of 1935?

Why all the forest dating to the years after 1917?

Friedman and Lee, 2002, Ecological Monographs 72, 409-425

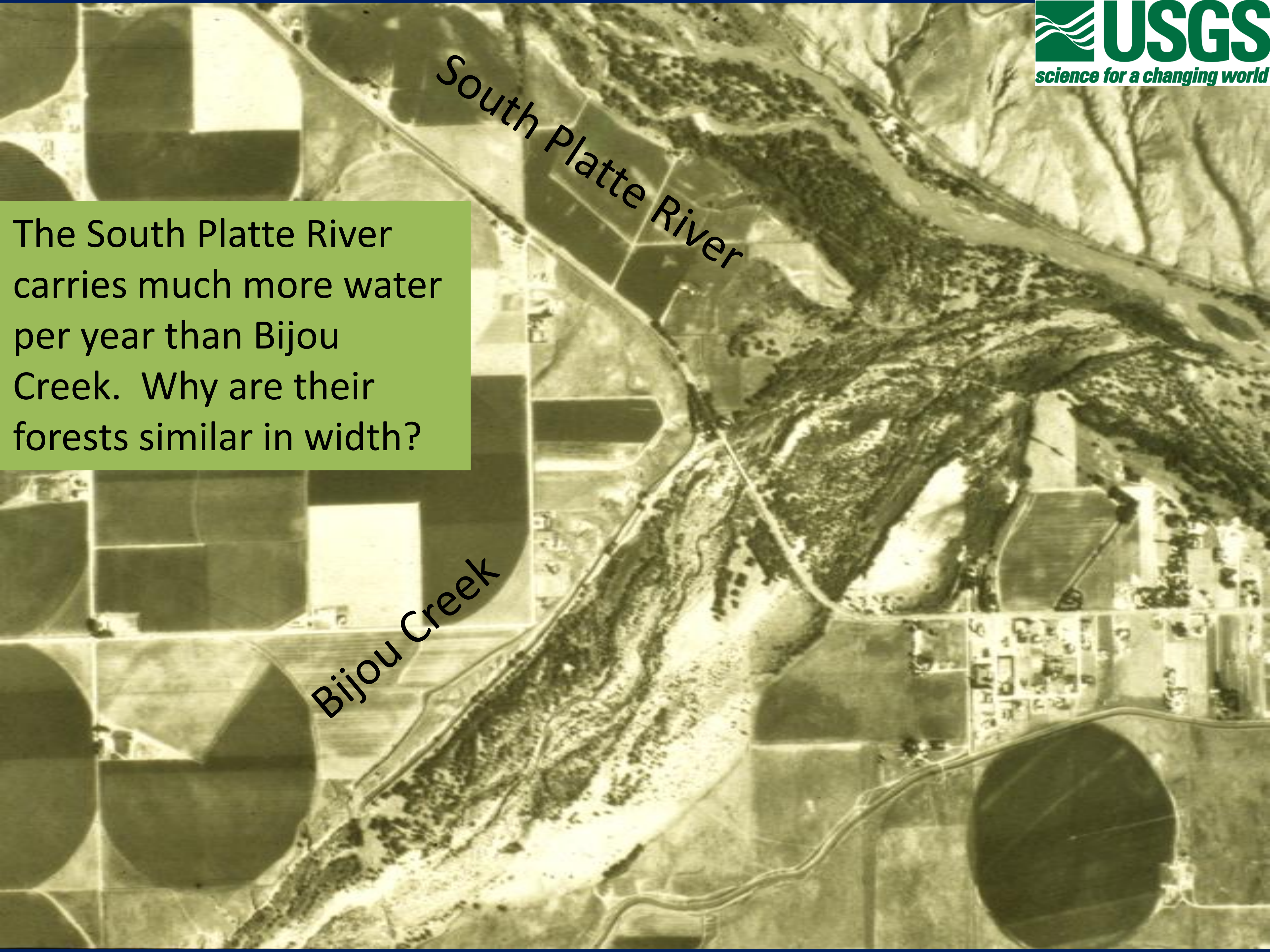
Coal, Creek, CO

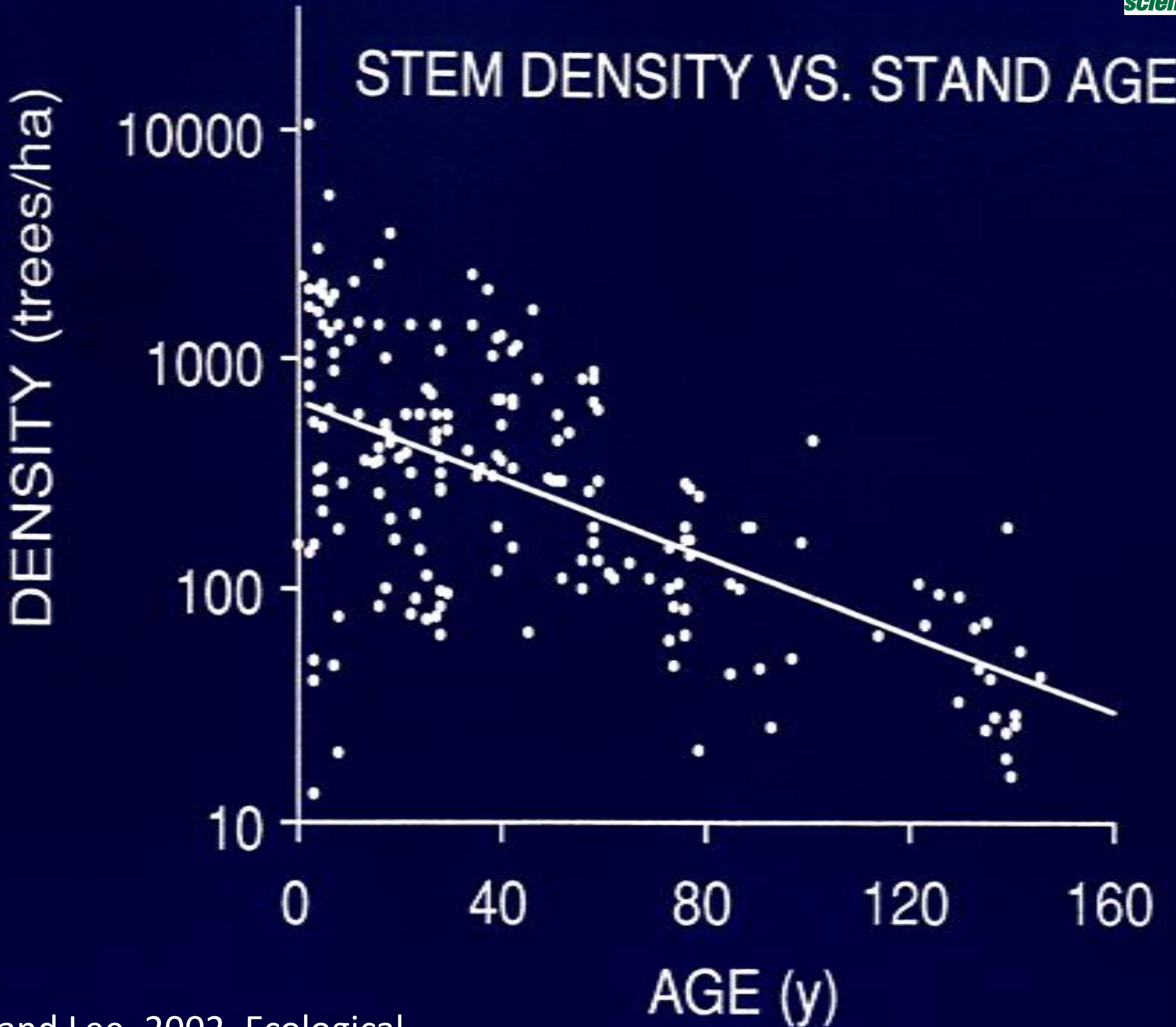
In the absence of flooding there has been little forest reproduction since 1920.



Friedman and Lee, 2002, Ecological Monographs 72, 409-425

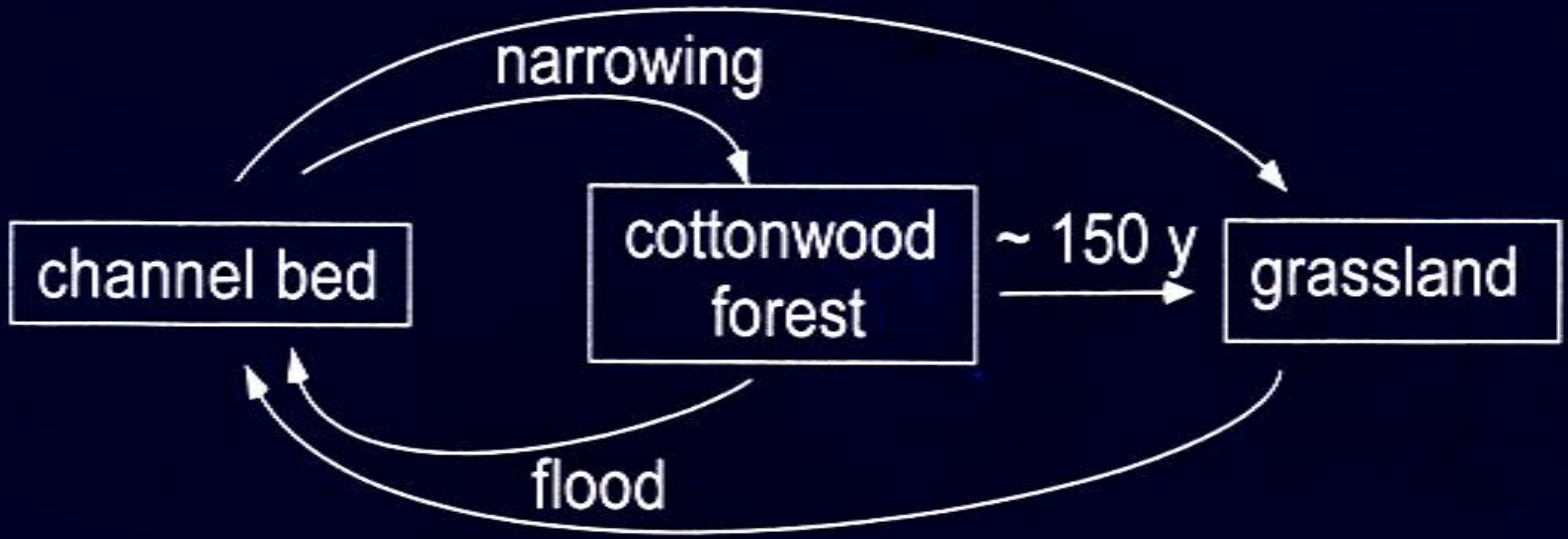
The South Platte River carries much more water per year than Bijou Creek. Why are their forests similar in width?





Friedman and Lee, 2002, Ecological Monographs 72, 409-425

BOTTOMLAND FOREST DYNAMICS IN EASTERN COLORADO

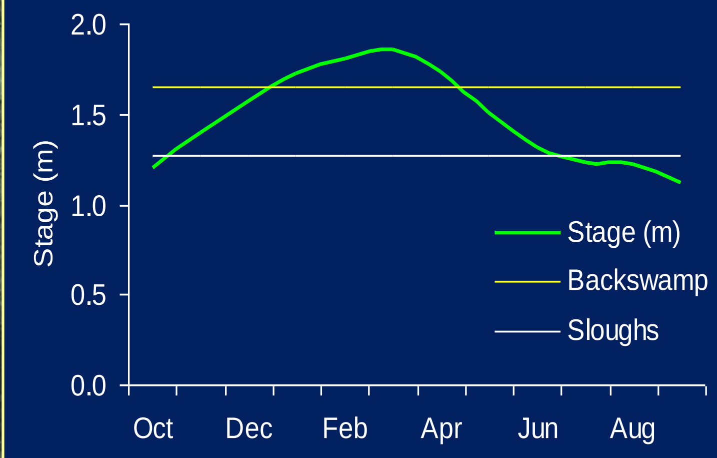


Friedman and Lee, 2002, Ecological Monographs 72, 409-425

Channels in Equilibrium with Extreme Flows

Alluvial fan in arid watershed, Wild Burro Wash, AZ
Flow from local, short-duration extreme precipitation
Very high variation in flow within and between years
Channel is in equilibrium with extreme floods; no recovery

In the humid southeast, annual floods last for months, and soil anoxia is extensive.

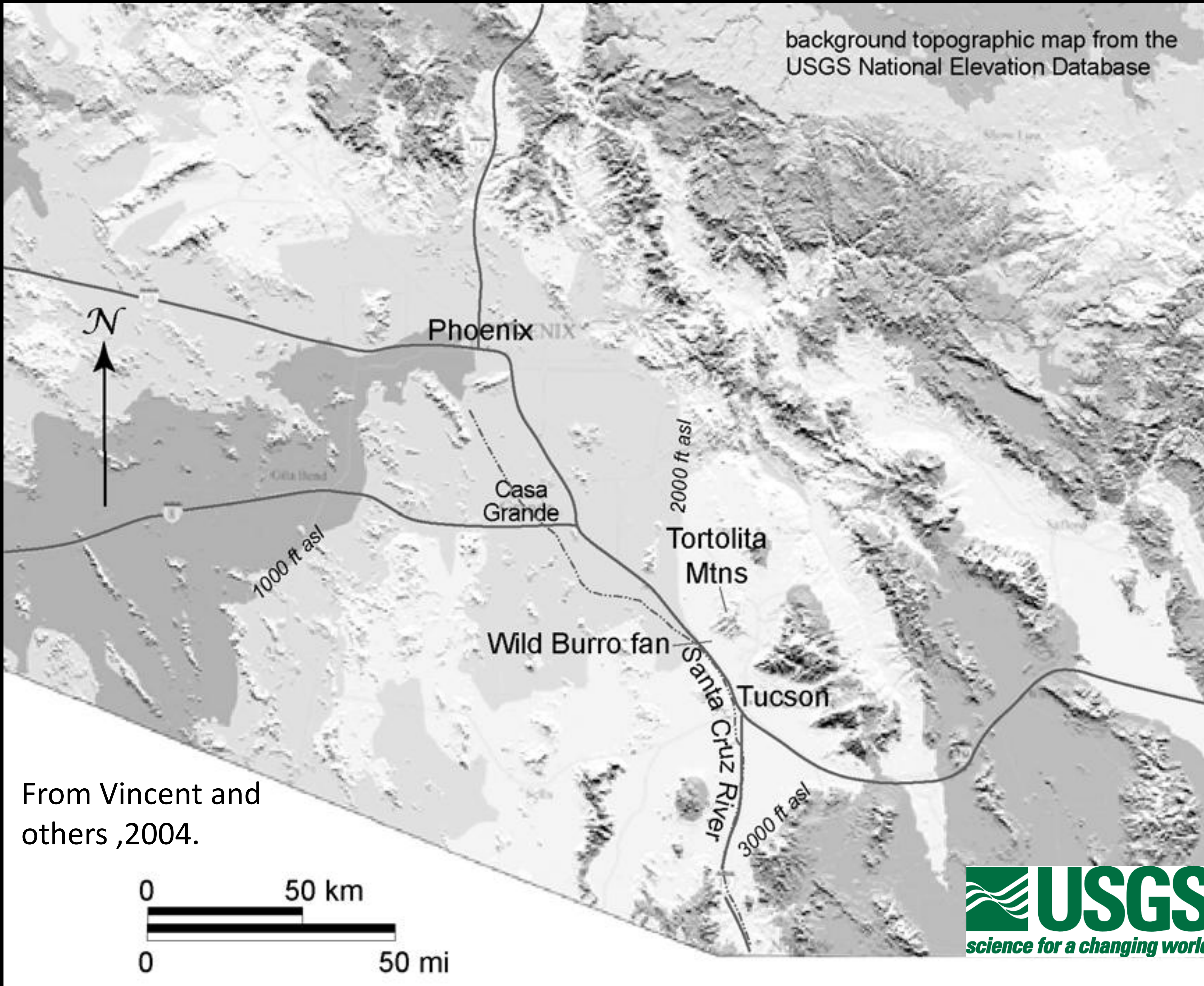


Spatial variation in water level in relation to site elevation

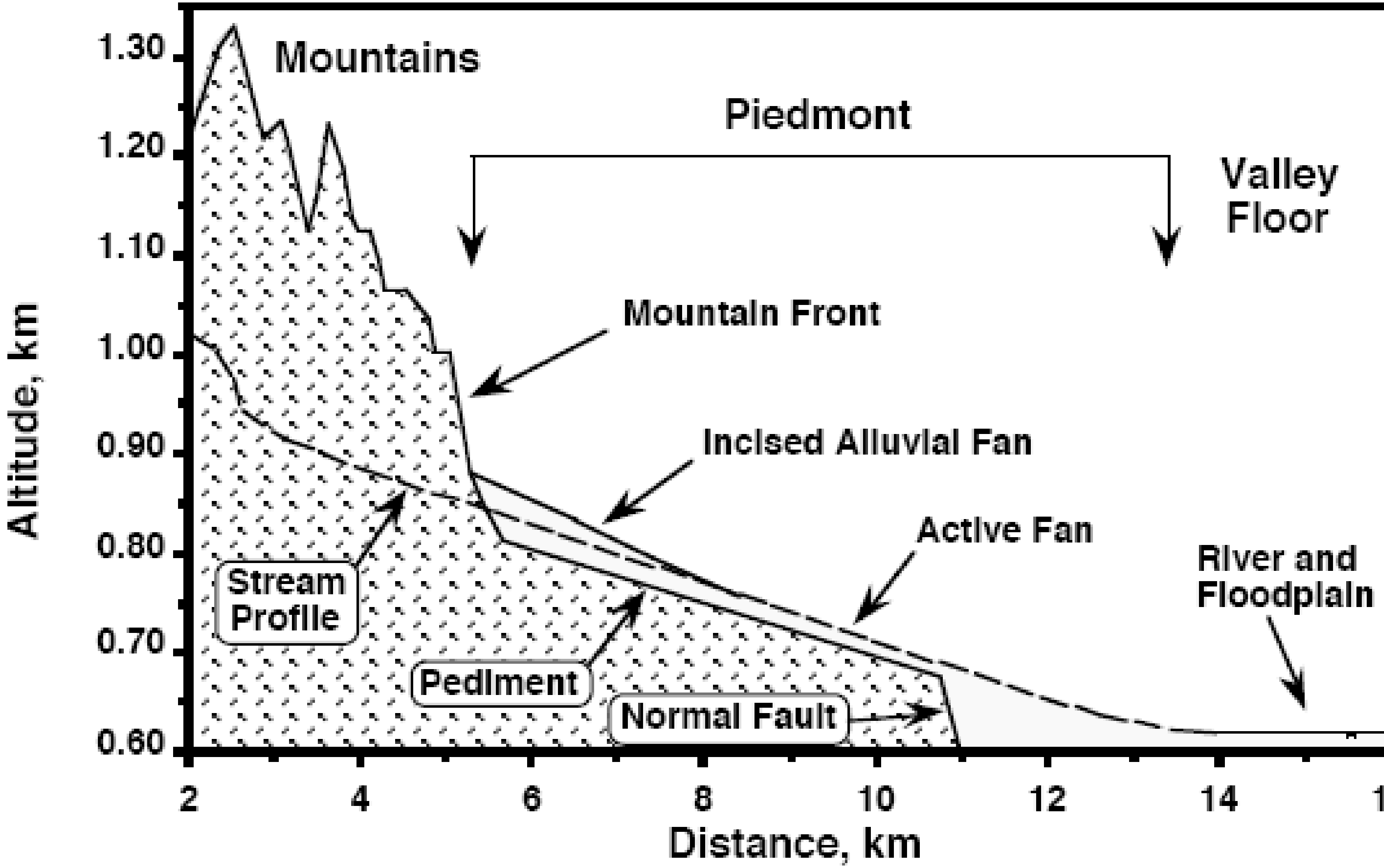
From Cliff Hupp

In the arid west, annual inundation of the flood-plain lasts for hours to days and does not occur every year. Forest may be restricted to the riparian zone: Bill Williams River, Sonoran Desert, Arizona

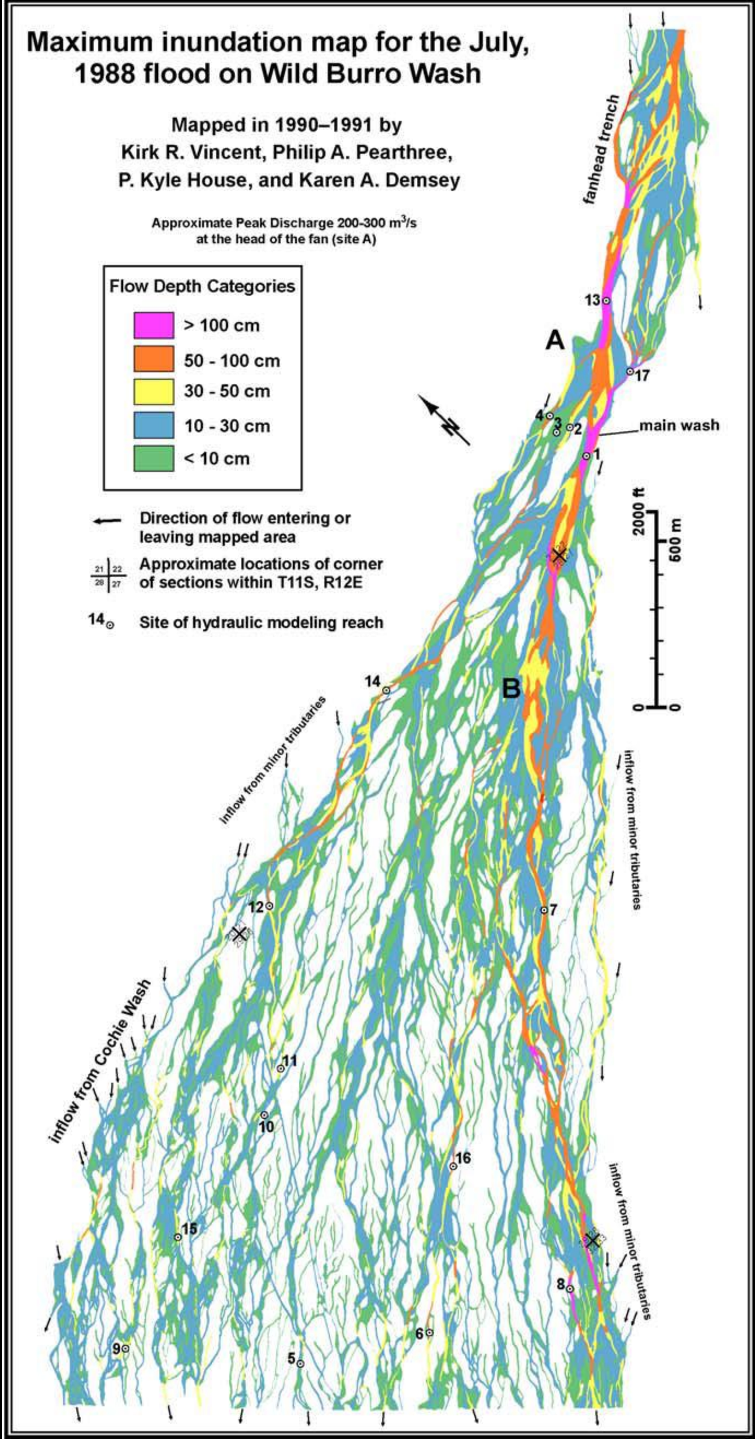
Anoxia is not extensive in space or time; Wild Burro Alluvial Fan, Arizona. This is a flood plain.



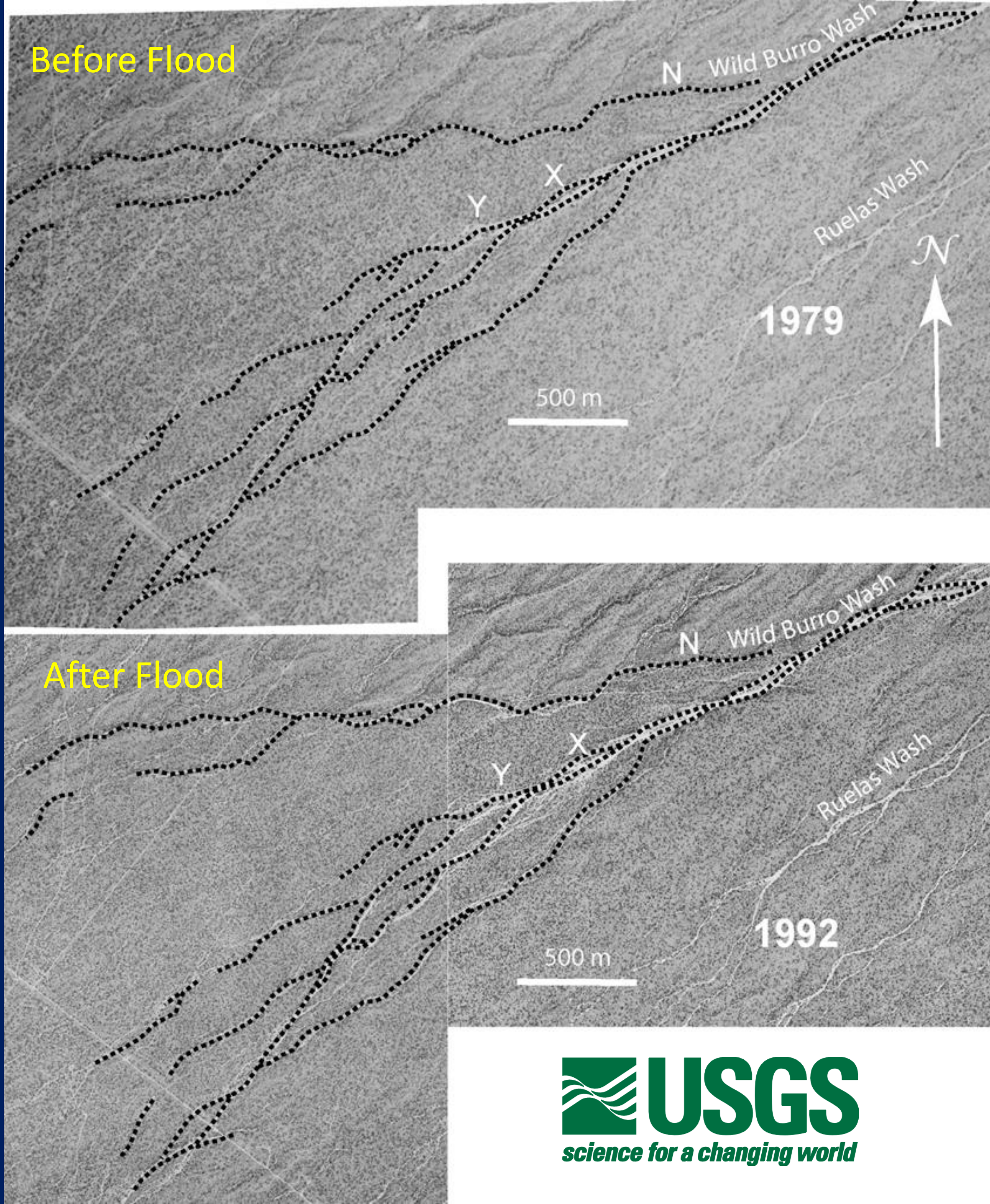
From Vincent and others ,2004.



Vincent and others, 2004.


Maximum inundation map for the July, 1988 flood on Wild Burro Wash
Mapped in 1990–1991 by
Kirk R. Vincent, Philip A. Pearthree, P. Kyle House, and Karen A. Demsey
Approximate Peak Discharge 200-300 m³/s at the head of the fan (site A)
Flow Depth Categories
> 100 cm
50 - 100 cm
30 - 50 cm
10 - 30 cm
< 10 cm
Direction of flow entering or leaving mapped area
Approximate locations of corner of sections within T11S, R12E
21 22 28 27
14
Site of hydraulic modeling reach
fanhead trench
A
B
main wash
2000 ft
600 m
0
0
inflow from minor tributaries
inflow from minor tributaries
inflow from minor tributaries
inflow from Cochie Wash
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

Channels mapped from aerial photographs before and after the flood of 1988, Wild Burro Wash, AZ. The flood did not change the channel. Recurrence interval was >100 years. Here recovery is so slow that channel is in equilibrium with rare floods. Avulsions occasionally cause major channel relocations. Vincent and others 2004.



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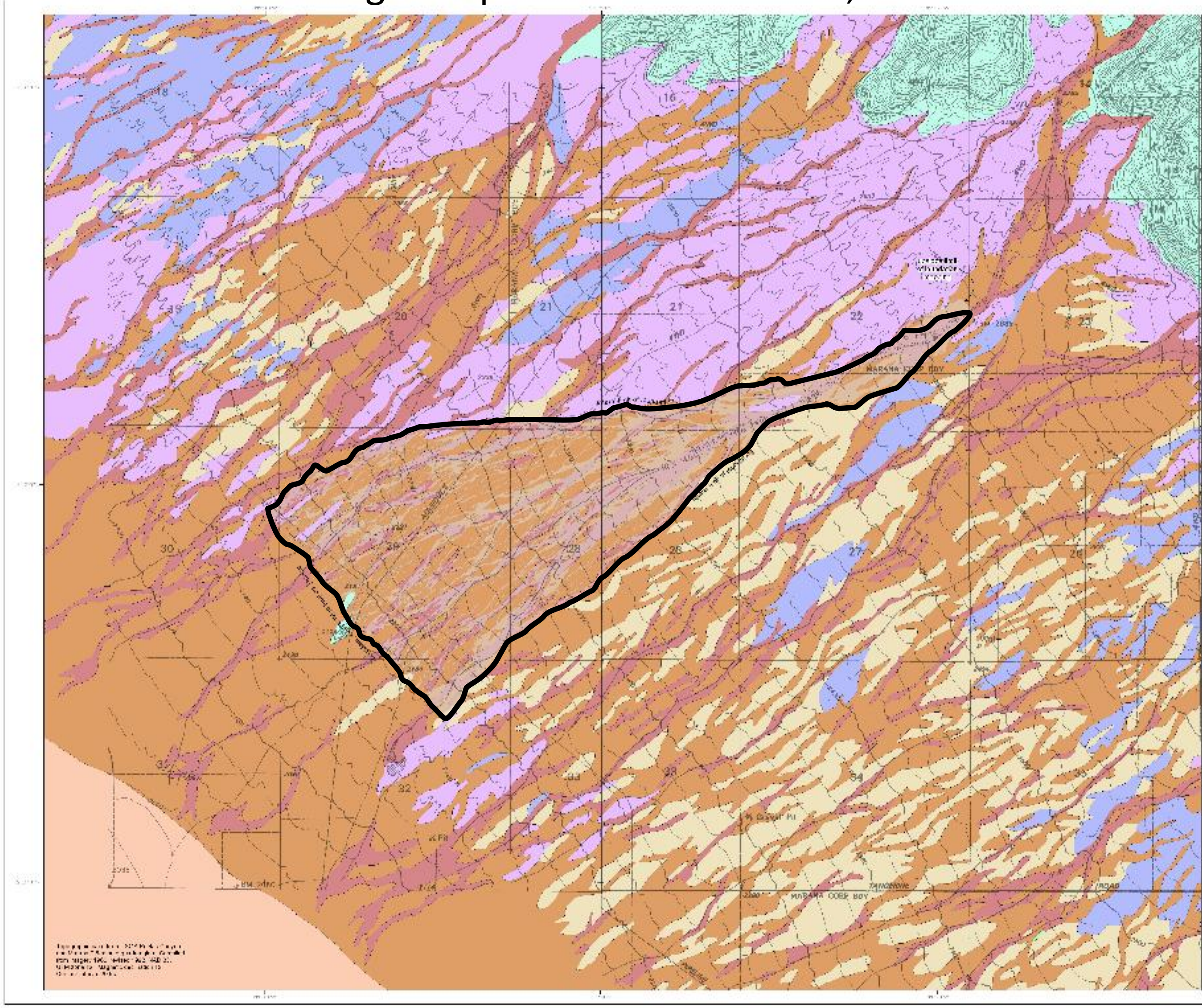
Surficial Geologic Map of Wild Burro Wash, Arizona

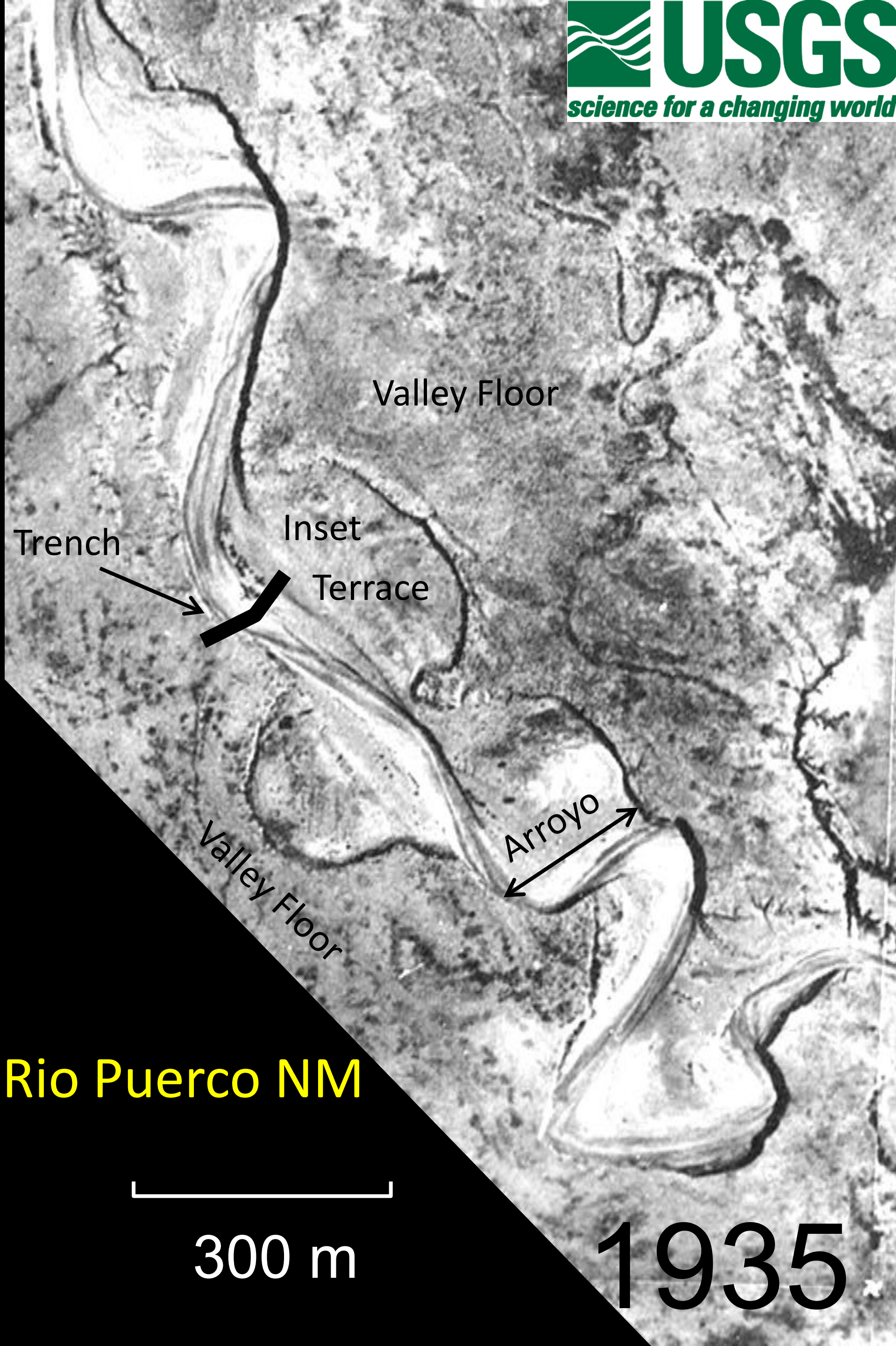


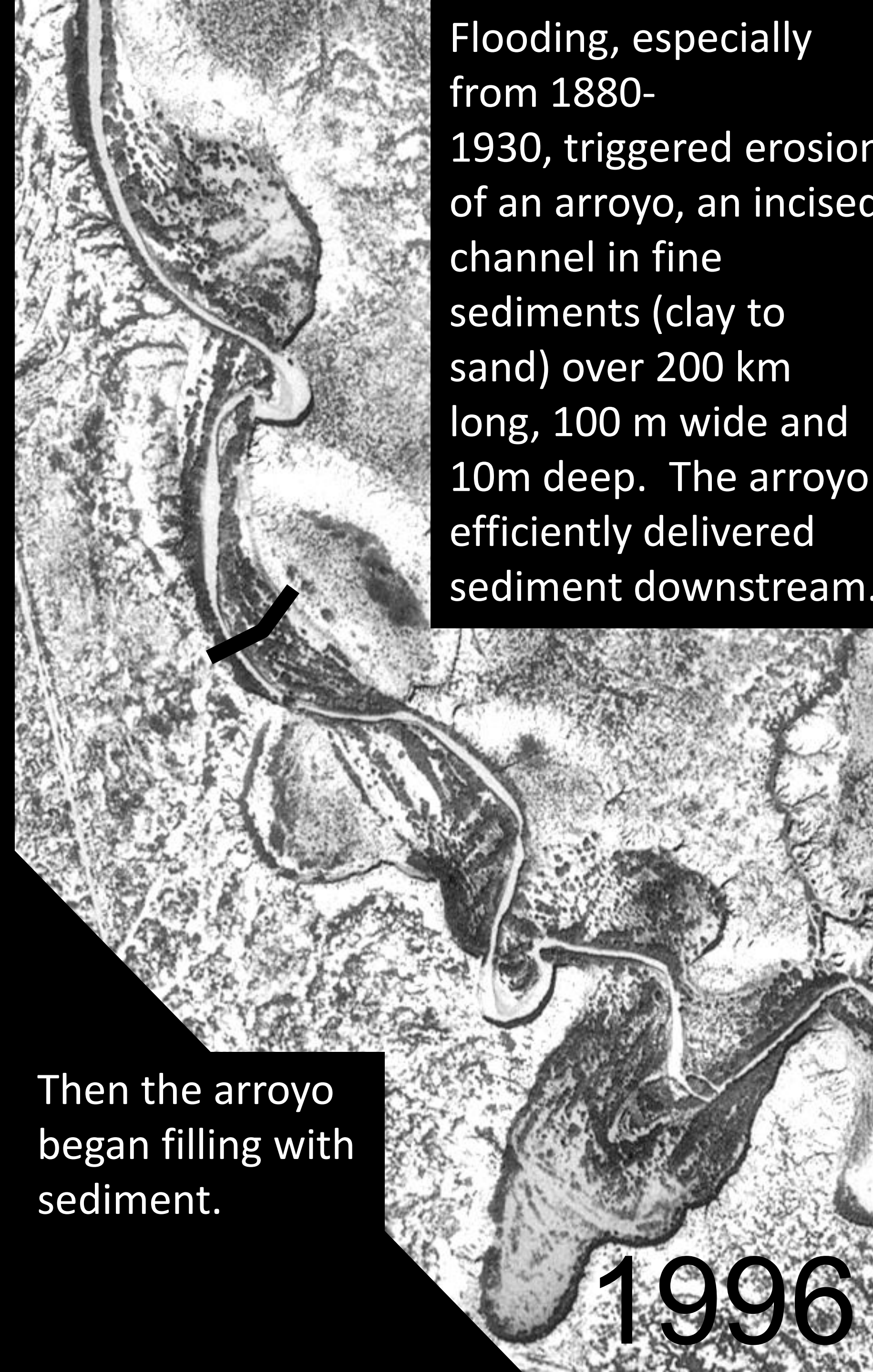
Because recovery is so slow, modern and ancient channels dominate the landscape. Geomorphic mapping forms a basis for land use decisions.

Vincent and others, 2004.

Time-Varying Channels Driven in Part by Internal Thresholds

- Arroyo in semi-arid watershed
- Flow from local, short-duration precipitation
- High variation in flow within and between years
- Arroyo cutting and filling influenced by precipitation and internal controls

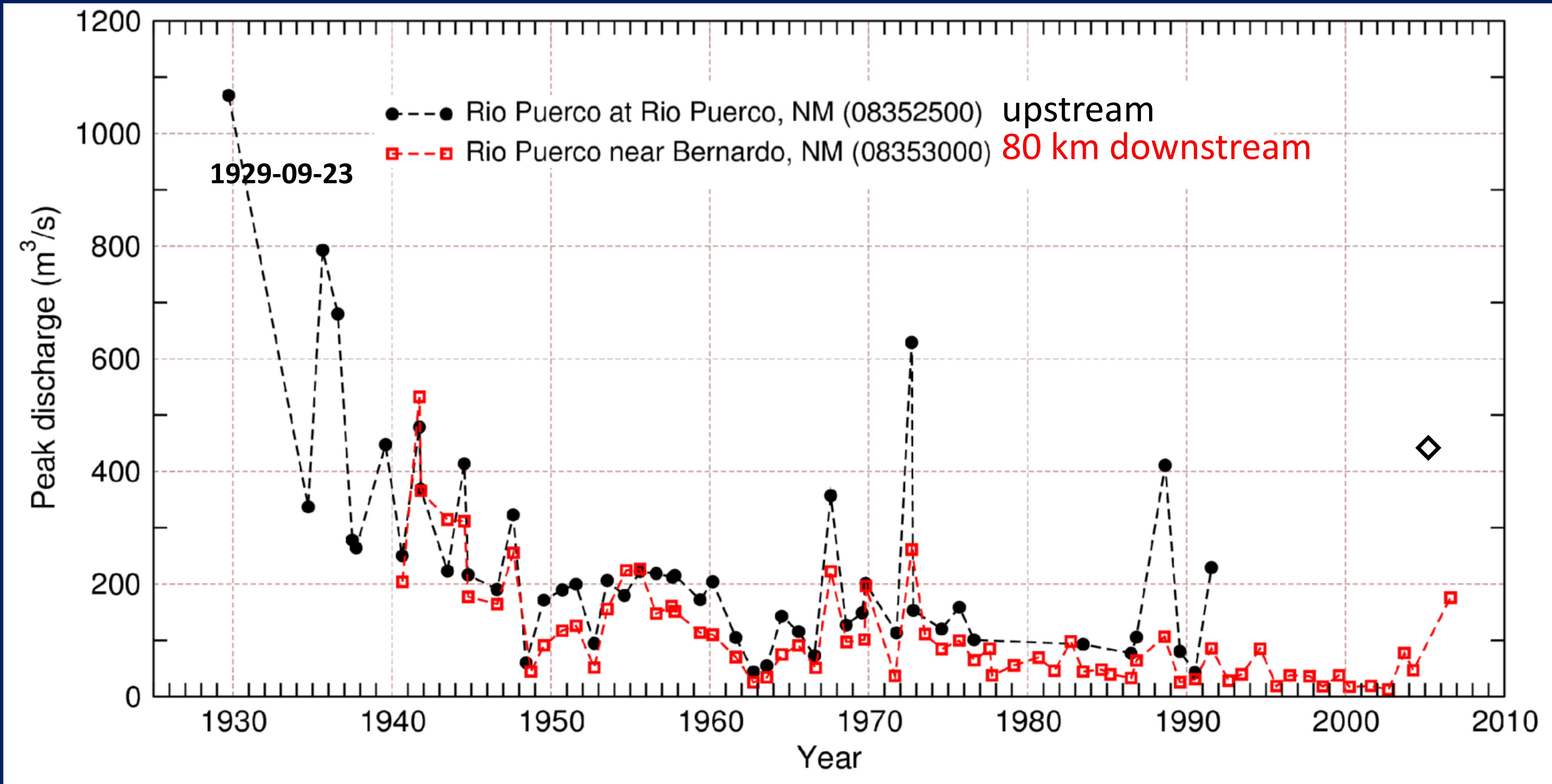




Flooding, especially from 1880-1930, triggered erosion of an arroyo, an incised channel in fine sediments (clay to sand) over 200 km long, 100 m wide and 10m deep. The arroyo efficiently delivered sediment downstream.

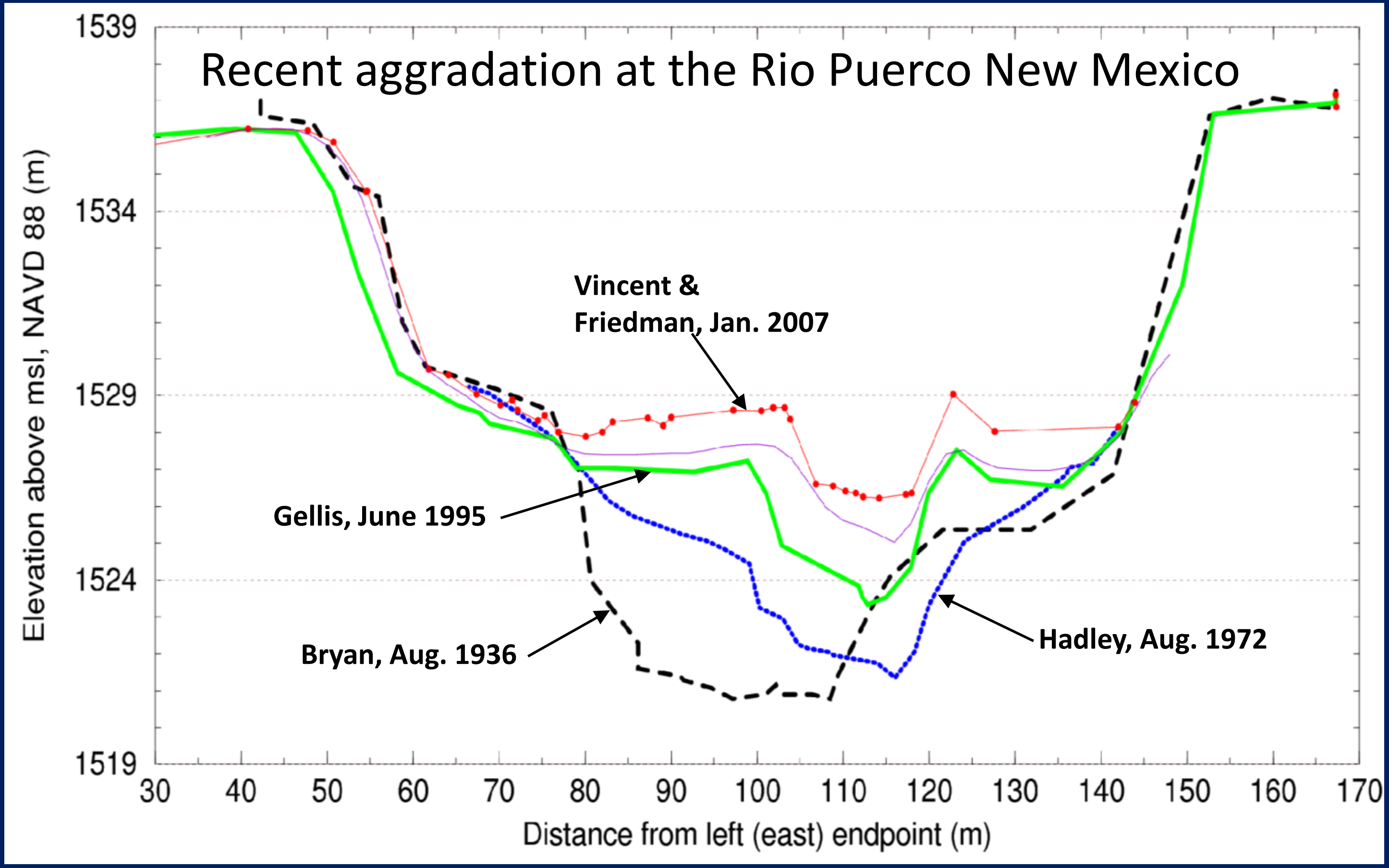
Then the arroyo began filling with sediment.

Peak flow data for the Rio Puerco, NM



Until about 1950 flows and sediment moved efficiently downstream.
After 1950 flows attenuated downstream and sediment was deposited within the arroyo.

The Rio Puerco transported flow and sediment efficiently between ~1880 and ~1930, but not before or after. Why?
Flow variation , tamarisk introduction, grazing controls, internal thresholds.



The purple line is derived from LIDAR data (2005)

Sediment transport capacity is proportional to unit stream power

$$\gamma QS/w = \gamma dvS$$

γ = unit weight of water
Q = water discharge
S = bed or energy slope
w= channel width
d = channel depth
v = velocity

If stream power is less than the sediment load the stream will deposit sediment

Cross section   Plan view   Cross section   Plan view

Low sediment transport capacity

depth in channel is low
Velocity is low
Slope is low

High sediment transport capacity

Depth in channel is high
Velocity is high
Slope is high

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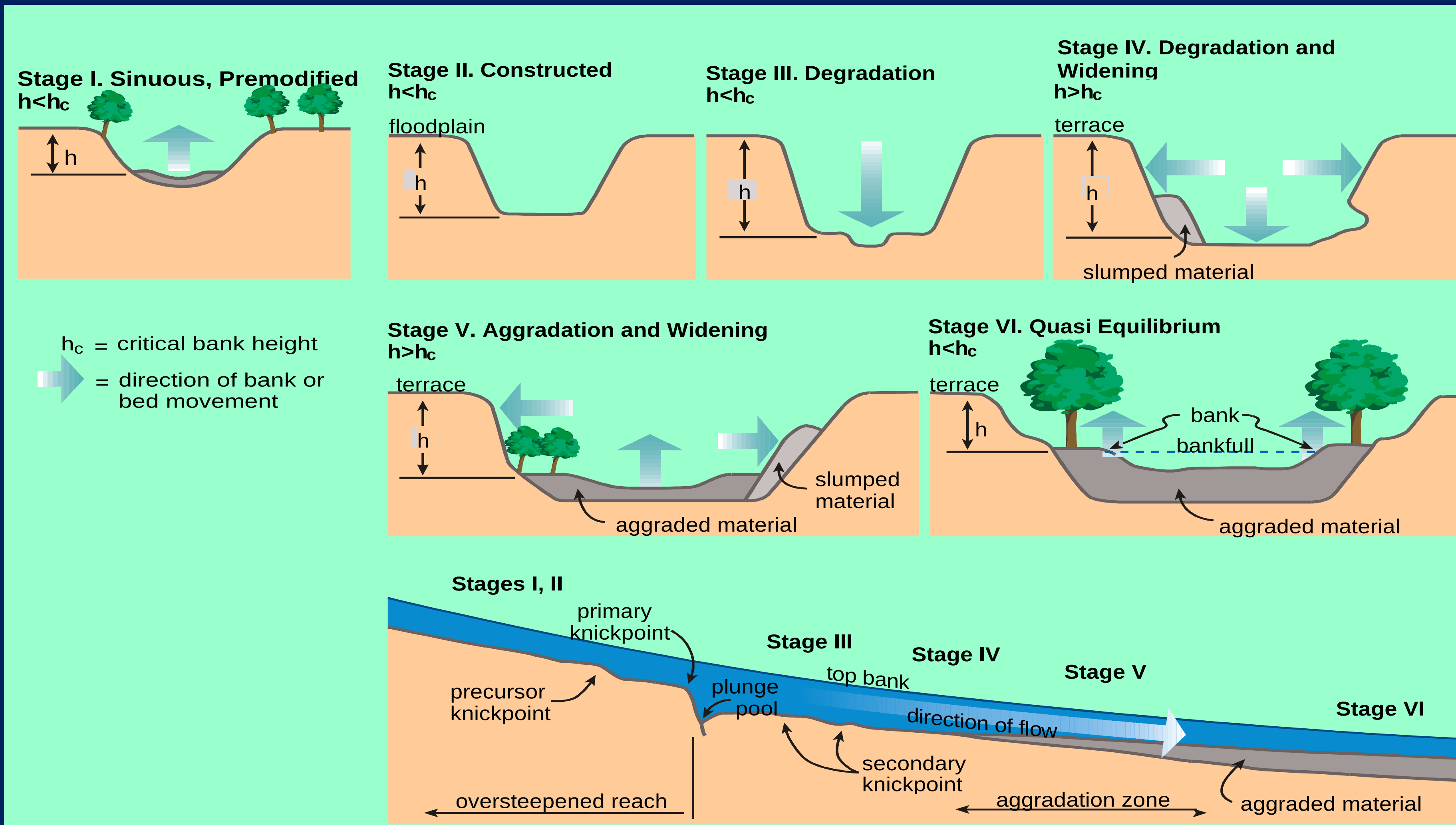
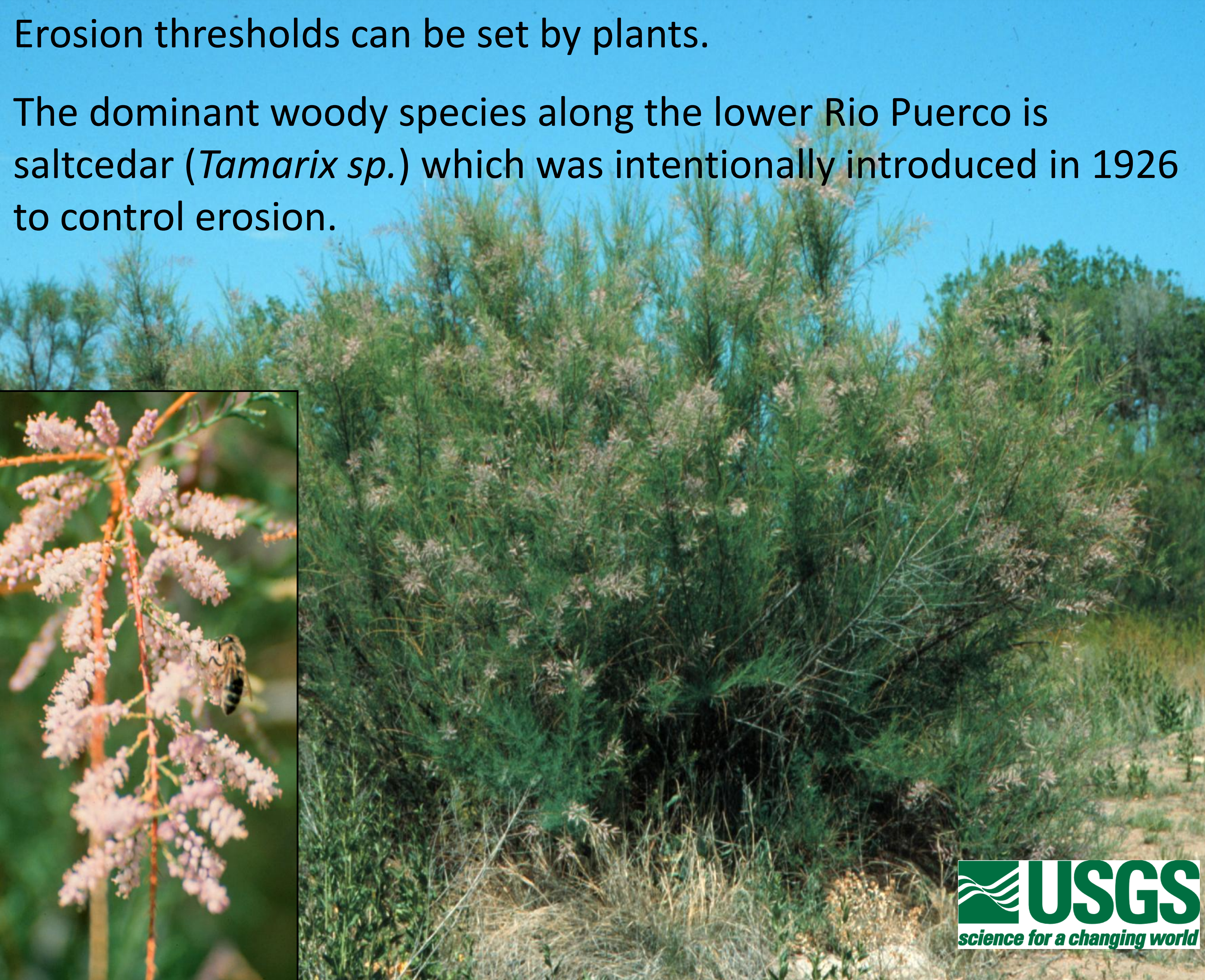
Stages of Channel Evolution
Once the process starts it proceeds to the end.



From Andrew Simon


Erosion thresholds can be set by plants.
The dominant woody species along the lower Rio Puerco is saltcedar (*Tamarix sp.*) which was intentionally introduced in 1926 to control erosion.
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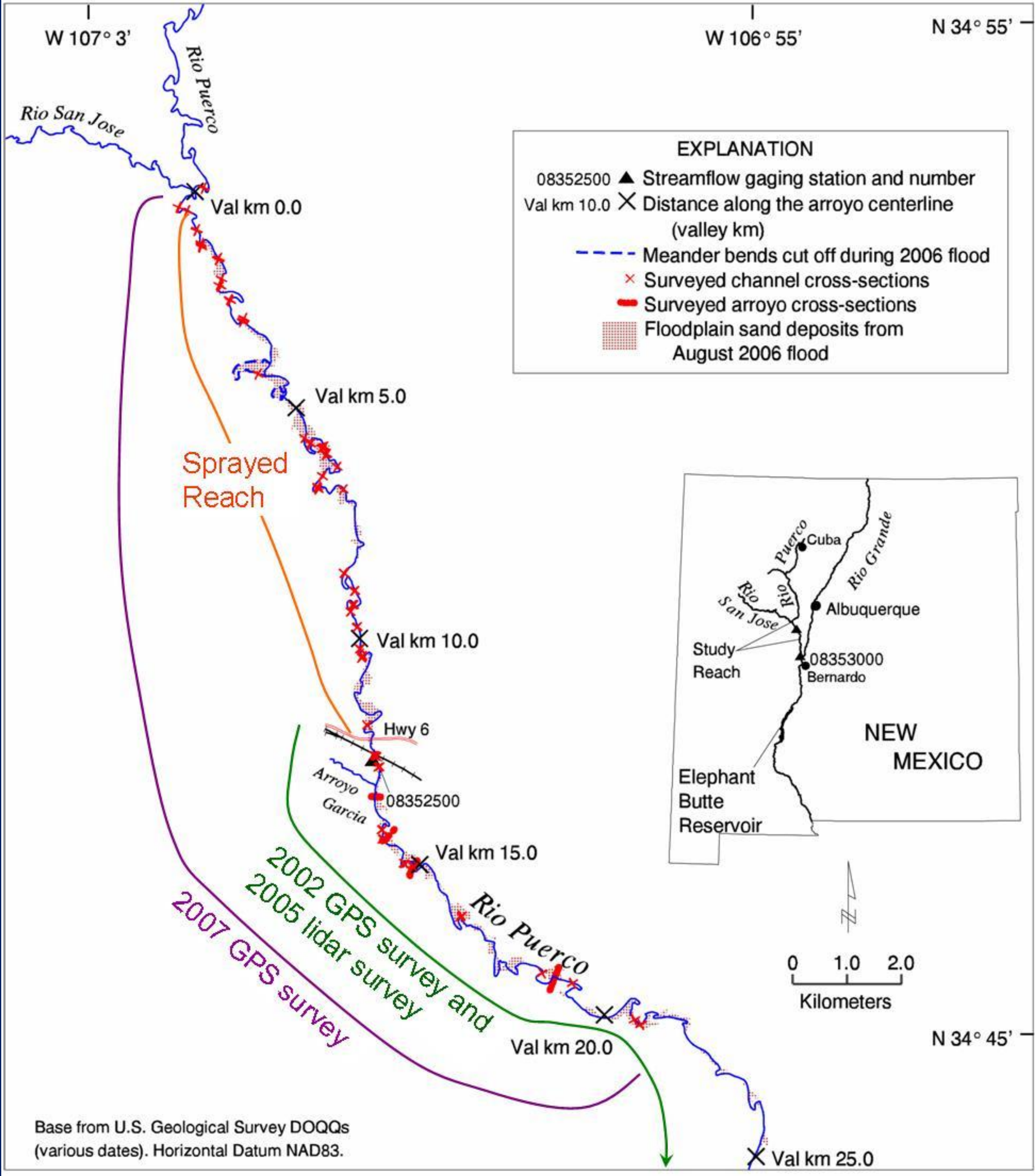
Rio Puerco flood plain, NM, 2001

A 12-km reach was sprayed with herbicide in 2003 to kill the invasive saltcedar and save water. This widespread technique has not been shown to increase stream flow (Shafroth, P.B., V.B. Beauchamp, M.K. Briggs, K. Lair, and A.A. Sher. 2008. Planning riparian restoration in the context of Tamarix control in western North America. Restoration Ecology 16(1): 97-112.)

In August 2006, the largest flood since 1972 occurred.



Channel bank and floodplain downstream from sprayed zone, October 2006. Fluid drag on vegetation decreases velocity near the bed, reducing erosive potential of flow.

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Channel in spray zone June 2005, before the flood

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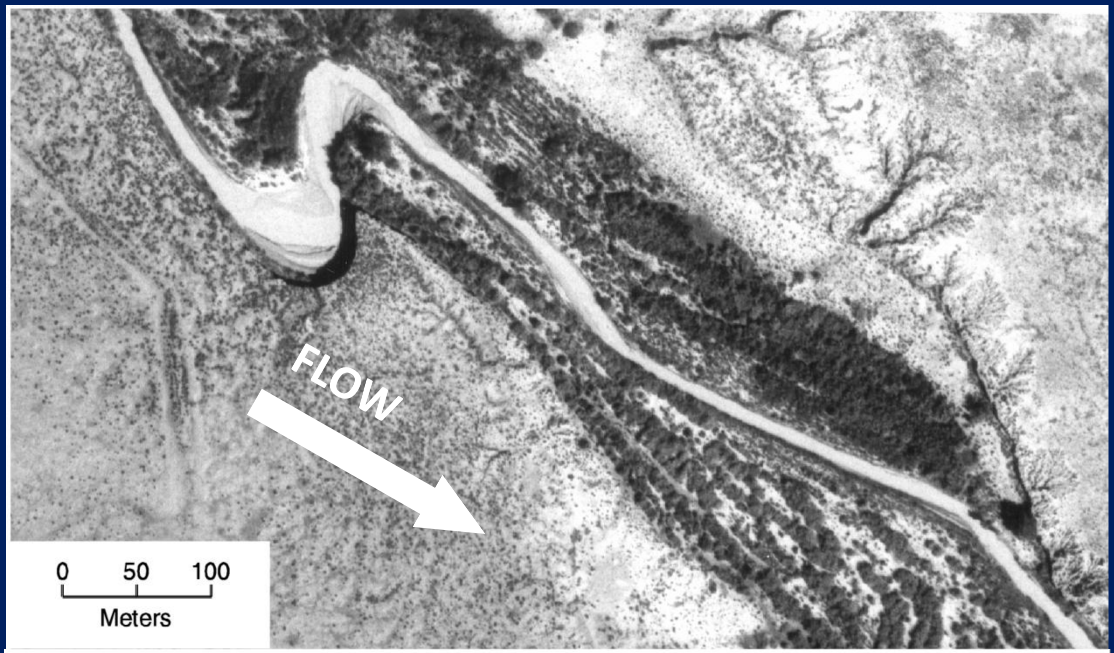
Flood erosion in spray zone. The left bank is intact; the right bank has been almost entirely eroded away. Removal of riparian vegetation reduced fluid drag at the toe of the bank, increasing velocities and shear stress. In addition, killing of roots decreased bank stability, promoting bank collapse.

Rio Puerco channel in the spray zone, Oct. 2006; erosion of flood plain on both sides of the channel.

Rio Puerco channel in spray zone, Oct 2006; erosion of flood plain and valley floor.

Aerial images of channel widening within the sprayed reach



October 1996 NAPP photograph

Average channel width 15.7 m

Nov. 2006 satellite image (DigitalGlobe)

Average channel width 35.7 m

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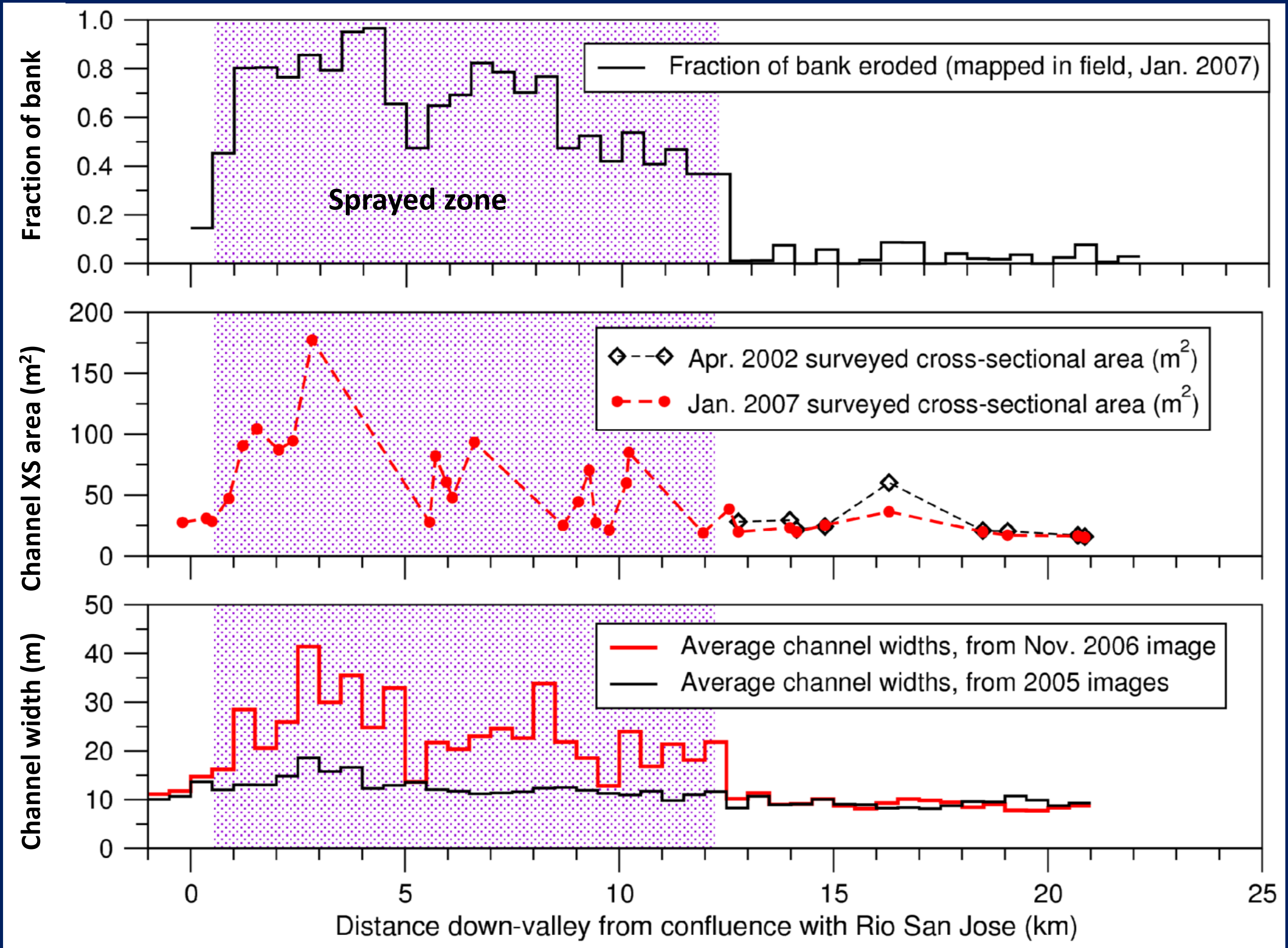
Channel bank erosion during August 2006 flood – mapped in the field and using imagery



Summary

Channels in dry regions are subject to episodic flow.

Because plants are sparse and flows between floods are low, channel recovery following flows is slow or nonexistent.

As a result channel form and flood-plain ecology may be dominated by extreme floods.

Sources

Friedman, J.M. and V.J. Lee. 2002. Extreme floods, channel change and riparian forests along ephemeral streams. Ecological Monographs **72**:409-425.

Friedman, J.M., W.R. Osterkamp, and W.M. Lewis, Jr. 1996. Channel narrowing and vegetation development following a Great Plains flood. Ecology **77**:2167-2181.

Friedman, J.M., K.R. Vincent, and P.B. Shafroth. 2005. Dating flood-plain sediments using tree-ring response to burial. Earth Surface Processes and Landforms **30**: 1077-1091.

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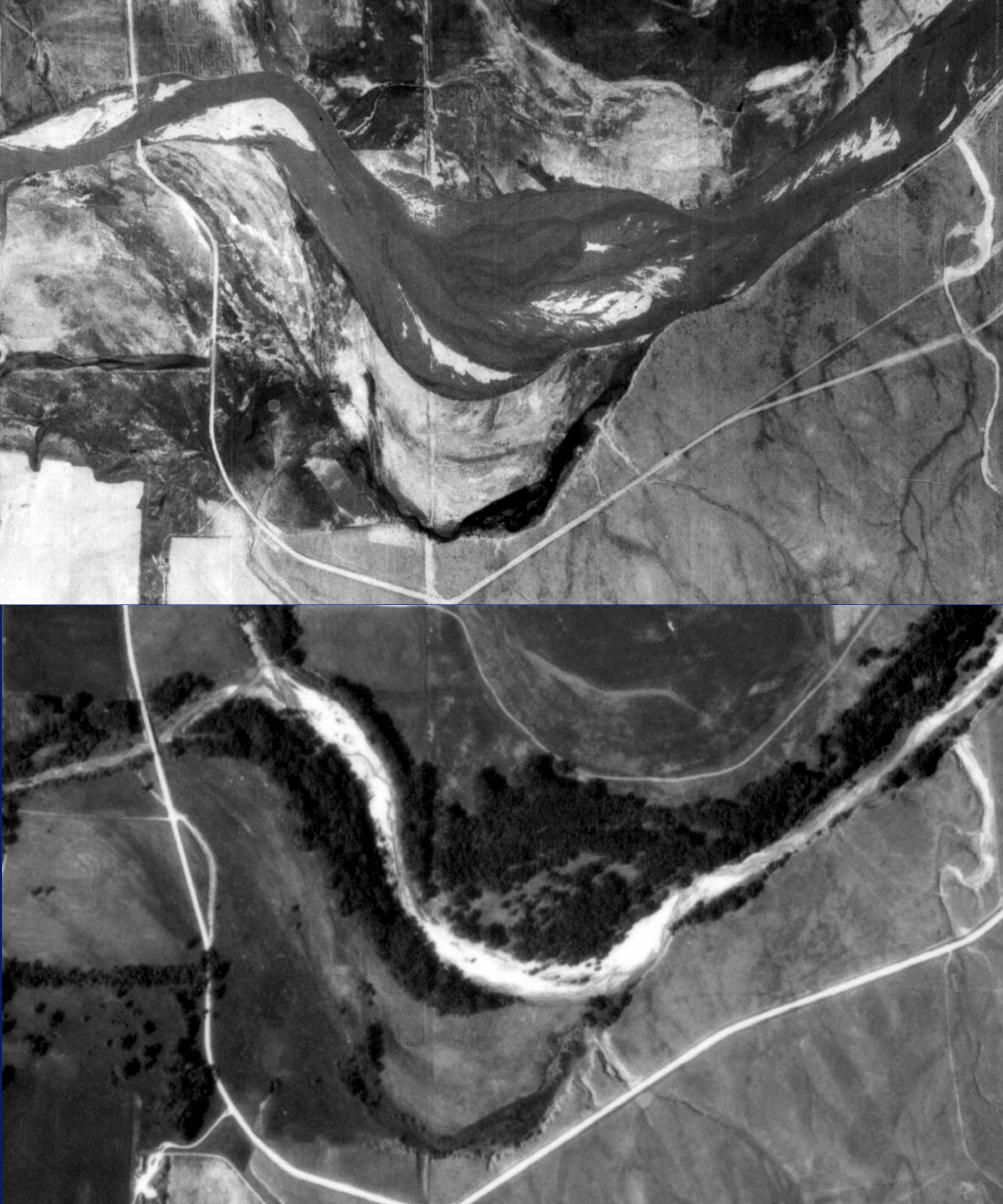

Flood widening, subsequent narrowing, and cottonwood forest establishment along the Arikaree River, CO.

From: Katz et al., 2005, Ecological Applications 15, 1019-1035